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GAS PRODUCTION IN YEAST FERMENTATION AND ITS APPLICATIONS. III. THE BAKING TEST

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This test has very likely been the subject of more discussion than any other test or group of tests employed by cereal chemists in the study of panary fermentation. It is therefore with hesitation that one attempts to add a word to an already lengthy chapter on a procedure which by its very empirical nature changes with the opinion of the individual workers.

We may state at the outset that the baking test, and by the baking test we mean the entire procedure from mixing of dough to staling of loaf, has proved an invaluable guide to us in at least five distinct directions: (1) blending of wheat, malt flour, and bleaching agents of the maturing type in the maintenance of flour mill specifications, (2) selection of flours best suited to the needs of individual bakeries and maintenance of uniformity in such selections, (3) study of supplementary ingredients, particularly milk and other improvers generally referred to as *dough conditioners* or *yeast foods*, (4) study of yeast, and (5) both pure and applied research. The test undoubtedly proves informative in other fields such as in the selection of new wheat varieties. These, then, constitute our reasons for employing the baking test and insofar as the test fulfills these expectations it will be useful. It is to be noted that the first of our applications of the baking test coincides with the first of its two purposes as seen by Fisher and Halton (1937). Our fifth application includes but goes far beyond their second purpose in that we do not necessarily observe dough behavior with the concept of flour utility in mind; rather, we are interested in the mechanism of that behavior. We wish to know not whether a flour is a short or a long fermentation-time flour, but why it is so and how we can make it otherwise. The second of our appli-

cations is similar to, though not identical with, that of the second of the two stated by Davis (1937). He employs the test as a means of finding the best baking procedure for a given flour, whereas we attempt to find the best flour for a given baking procedure. Landis and Frey (1936) also claim two fields of usefulness for the baking test, their first coinciding with the first of Davis (1937). They employ it as a means of evaluating characteristics which can be determined in no other way. This we take to be self-evident, except that the question as to which characteristics fall into this class remains unanswered. Their second is that the baking test serves as an overall check upon factors determined by other methods. It occurs to us that these other methods must be poor indeed if the baking test must serve as a check upon them, in view of the statement of Davis (1939) that collaborative studies of the baking test were so discouraging as to make it inadvisable to continue the collaborative work. In reference to this, one may conclude with Blish (1936) that standardization at least of the mechanics of the baking test must and will in due course of time precede successful experimental agreement among individual laboratories.

Type of Procedure

Much has been said in recent years concerning the mode of attack to be used in designing a baking test. Davis (1937) speaks of two schools of thought, that which adheres to a *fixed* and that which adheres to a *variable* type of procedure. Landis and Frey (1936) distinguish between *fixed ingredients* and *fixed factors*. They indicate that either the ingredients or the factors but not both may be fixed. With this premise we are in complete agreement; with the deduced consequences, however, we find a tendency toward reaction to a now in a sense obsolete school of thought, namely, that one which strives to approach *optimum conditions*. In this school we may place those who attempt to duplicate commercial bakery practice, since the baker ever strives for optimum conditions. Hence, the *optimum condition* school survives as the true philosophical opponent of the *fixed condition* school, which itself is now divided into two subgroups of *fixed ingredients* and *fixed factors*. That *fixed factors* are far more to be desired than *fixed ingredients* has been excellently demonstrated by Landis and Frey (1936) as well as by many others. So much then is clear, but it is also true that the subtle dangers inherent in the technique of fixed factors have not received their warranted publicity. To this we will return after first discussing the apparent position of those who argue for *optimum conditions*.

Optimum vs. Fixed Conditions

Proponents of the *optimum condition* school hold that the experimental conditions should be so varied as to permit a flour in question to display its utmost virtues; that is, the optimum conditions of all controllable variables must be found before practical interpretations concerning flour utility can be drawn. It is at once apparent that this technique by its very nature is subject to scientific treatment only under two distinct sets of conditions. The first demands that individual tests be performed for each complete set of permuted variables. This, the so-called *Latin-square technique*, demands practically unlimited materials and unlimited time, and hence is of little practical significance. It may be argued that the judgment of the individual experimenter is such that many of the variables legitimately may be neglected because of automatic intuitive compensation for their various interactions. That is, it is unnecessary to perform the baking test for that group of permuted variables in which the fermentation period, for example, is varied by definite increments of time, because the intuition of the experimenter will more likely than not indicate the proper and optimum fermentation time.

There may be some who will question the use of the word *intuition*. They will say that the experimenter judges the time necessary for optimum fermentation after due consideration of the observable characteristics of the fermenting dough. The mental road, nonetheless, remains intuitive in nature as long as the experimenter does not understand at least the pertinent causes and mechanisms involved in the production of the observed characteristics.

That this is so, is an experimentally demonstrable fact. It is not uncommon to find independent fermentation experts in earnest disagreement as to the *youth*, *optimum*, or *age* of a fermenting dough. Their disagreement often becomes more marked upon comparison of their opinions of the finished loaf. Some loaves are said to have *old* characteristics, some *young*, and some are *young* in certain respects while *old* in others. This has been borne out beautifully on several occasions by the following technique. Two series of six loaves each were prepared by the sponge-dough procedure shortly to be described, the first series from 3½-hour sponges and the second from 12-hour sponges. The resulting loaves were presented to two men thoroughly familiar with the practical aspects of dough fermentation. In this instance, they both agreed that the loaves produced from the 3½-hour sponges possessed symptoms of *age*, while those produced from the 12-hour sponges possessed symptoms of *youth*. When their error in judgment was pointed out, they parried by asserting that the loaves produced from the 12-hour sponges were so *old* they had reclaimed the

symptoms of excessive *youth*. One finds no argument with this possible caprice of nature, but does find scientific unreliability in the technique that permits ambiguous and ill-defined judgments.

This process of reasoning permits us to arrive at two conclusions. First, it is humanly impractical to study all the permuted variables in the attempt to find the optimum conditions for a given set of raw materials. In fact, it is humanly unattainable, since an infinite number of variables is involved. Second, the problem may not be simplified with legitimacy by trusting to the uncertainties of the experimenter's judgment. To do so transports the study from the realm of science to that of art.

We may now turn to the second set of conditions necessary to permit the study of flour or supplementary ingredients under optimum states of all concerned variables. This demands that we first study complete sets of permuted variables sufficient in number to permit us to arrive at the general laws involved; that is, before any routine study of flour or supplementary ingredients is approached, we attempt to develop some understanding of the fundamental causes and mechanisms involved in the production of observable characteristics. Once these laws are evaluated, it will no longer be necessary to study each of the infinite groups of variables, but some selected few will suffice to permit us by deductive reasoning to determine the optimum conditions of variables for the particular ingredient under consideration.

Hence to apply scientifically the method of the school demanding optimum conditions, we must first obtain some analytical understanding of the physical, chemical, and biological aspects of fermentation. This it must be agreed we do not as yet possess. Hence we are led to conclude that necessary preliminary work must precede the application of this technique to the scientific rather than the artistic study of flour as well as to the study of supplementary ingredients. But if we wish to continue with the concept of optimum conditions, the pathway is clear. We must first acquire the necessary understanding of the processes of fermentation and this may be attempted by working under fixed conditions, permitting only one variable to change at a time. We may thus study the effect of the given variable and make the opportunity for discovering the laws connecting the observable characteristics with each of the variables concerned.

It is to be hoped in fact that appropriately directed study will lead to the solution of a significantly large number of such relationships and ultimately to a solution of the complete relationship. But this is just the procedure advocated by the second of the two schools of cereal chemists. It would seem, then, that the continued existence of these two schools of thought is not particularly conducive to the rapid

development of the science of cereal chemistry. This difficulty may well be illustrated by a study of much of the published data. These cover a multitude of conditions and a multitude of interests. Relatively few, however, represent an exhaustive study of some single effect. Hence if one desires to generalize and ascertain even elementary principles, he is at a loss through lack of correlative data.

The Standard A.A.C.C. Baking Test was originally designed with concepts similar to these in mind. Unfortunately, the *optimum condition* school has had its influence even here. For example, the Tentative Baking Test as published in the third edition of *Methods of Analysis* of the A.O.A.C. in 1930 requires that absorption be kept constant, while the 1935 edition of *Cereal Laboratory Methods* suggests that absorption be varied to suit the flour; that is, the resulting dough must be neither too slack nor too stiff. No criterion for judging this will-o-the-wisp, however, is indicated. Variation of absorption to suit the flour is taken to mean optimum absorption.[1] But whether by this is meant that absorption which produces the optimum grain or optimum volume, or optimum loaf (itself as yet not quite defined) or yet perhaps optimum mixing characteristics, is left to one's intuition. But it is just this procedure which has been shown to be unsound. It might prove well worth while to reread the article entitled "The Baking Test," by E. E. Werner (1925).

One final thought in regard to this matter is perhaps suggestive. It may be granted that over a period of years a selected group of individuals will gather sufficient experience to warrant respect for their judgments concerning optimum fermentation time, temperature, absorption and the like; and their interpretations of flour and supplementary ingredient characteristics will prove as sound as their judgments. Nonetheless, their results remain irreproducible by fellow workers, and at the same time relatively useless as data upon which theoretical study of general principles can be based. It would seem that this same selected group of individuals, rather than sharpening their senses in the direction of nonuniversal, artistic irreproducibles, might better have spent their years developing similar sharpness of intuition in the direction of interpretation of results obtained under fixed, universal, reproducible conditions. *A priori*, their chances for success by route of this second procedure are at least as great as their chances for success by the first procedure, and at the same time their compiled data could serve as a foundation for fruitful penetration into the sundry mechanisms of fermentation.[2]

[1] See Markley and Bailey (1938) for a discussion of this point.

[2] The preceding discussion may very likely have some bearing on an often repeated criticism of the basic test. To quote Markley (1940): "The basic test, as devised by Dr. Werner, was a test of diastatic activity or gassing power of a flour rather than the strength." It occurs to us that Dr. Werner

We may now decide that whether our interest lies with flour characteristics or with supplementary ingredients, our choice of procedure must be restricted to those that permit working under fixed, reproducible and certainly standardized conditions in which only that one of the variables which is under immediate scrutiny is permitted to change. Different workers in different localities studying the same effects must obtain at least correlative if not identical data. Those factors which disturb this possibility should be studied one by one so that adequate corrections for uncontrollables like barometric pressure and yeast variations can be given due consideration in interpretation of data.

Fixed Factors vs. Fixed Ingredients

Having already conceded the validity of the arguments of Landis and Frey, we return to the dangers inherent in the method of *fixed factors*, and to the necessity of avoiding the road towards *optimum conditions*. We perceive two major pitfalls.

The first is elementary, though nonetheless overlooked. We take the case of determining the potential sugar level of flours prior to their study via the baking test. These authors indicate an empirical method for determining the potential sugar level and advocate varying the ingredient sugar among the flours so that all will have a common potential sugar level. They give directions for determining either the amount of sucrose or of nondiastatic malt to be added. But Larmour and Bergsteinsson (1936) have shown that the rate of gas production is affected differently by sucrose than it is by maltose. Further, Sandstedt and Blish (1939) restate their earlier findings that a common sugar level does not guarantee a common rate of gas production. Larmour and Brockington (1934) also have shown there is a response due to sugar independent of its effect upon gas production. By controlling only the potential sugar level, therefore, we cannot control the rate of gas production. Further, there is no reason to believe that controlling the potential sugar level without due consideration of the kinds of sugar will eliminate the specific effect of Larmour and Brockington.

The work of Kuhlmann and Golossowa (1936) on bound water as affected by maltose may be of interest in this respect. In addition,

himself very likely was familiar with other more satisfactory physical and chemical methods for the determination of diastatic activity or gassing power and hence would not have used the relatively cumbersome baking test for this purpose. It further occurs to us that, realizing the hopelessness of the *Latin-square technique*, he may have tentatively selected the basic test as one distinguished by the highest return in information for the amount of labor involved; that is, diastatic activity was learned and this information used in the interpretation of volume and so on. Data obtained by the quantitatively fixed procedure of the original basic baking test are but a step from possessing absolute significance, in contradiction to the opinion expressed by Markley. The whole argument hinges upon the position of judgment. Shall we employ judgment after the data, in a fixed and universally reproducible manner, are acquired? Or shall we employ judgment before the data are acquired?

this laboratory has found the rate of gas production particularly in straight doughs to be somewhat sensitive to variations in sucrose. This effect as will be shown in a subsequent communication is often negative during certain periods of fermentation and very likely explains the negative volume response to sucrose found by Sandstedt and Blish (1939) for flour number six. That is, with a wheaten dough as substrate, maltose fermentation is inhibited by sucrose. This further explains the observation of Bohn and Favor (1939), "that the rate of gas production is faster during the third hour when no sugar is present than at any other time." The work of Schultz and Atkin (1939), however, in which dextrose is found to *stimulate* maltose fermentation cannot be considered in disagreement with our findings, since their buffered liquid substrate presents an entirely different environment for the fermentation.

We may conclude, therefore, that though it is desirable to have all flours at a common sugar level, the method of Landis and Frey does not serve satisfactorily; the problem is far more complex than indicated by them. Certainly a common rate of gas production during the proofing period is more to be desired than a common empirical potential sugar level. The first pitfall, then, lies in too quickly applying a means for controlling a factor at the expense of an ingredient when sufficient knowledge concerning that factor is not at hand. The method suggested by Sandstedt and Blish (1939) of supplying an excess of sucrose and proofing to constant height very likely is more satisfactory, though we may here indicate that we have reason to believe that employing an excess of maltose rather than sucrose with the simultaneous addition of about 0.07% ammonium chloride will bring most flours to a common and relatively constant rate of gas production during the third hour of fermentation, all other factors abiding by the A.A.C.C. procedure.

We may now turn to the second and more subtle pitfall that must be avoided in attempting to fix factors rather than ingredients. Varying absorption to suit the flour has already been mentioned. Landis and Frey (1936) indicate that flours may vary from 57% to 75% in this respect. They do not mention, however, that because of the unfortunate manner in which cereal chemists compute percentages, the actual yeast content, sugar content, salt content, and protein content of the dough are forced to vary as the absorption is varied. We compute that yeast will vary from 1.875% of the dough weight in the low absorption flour to 1.685% of the dough weight in the high absorption flour; that is, the former will contain 11.3% more yeast than the latter. The question is one of selecting the factor to be fixed. Certainly constant water content of the dough is desirable, just as con-

stant potential sugar level may be. Shall we select constant water content or constant dough consistency as the factor of interest? The former can be determined with relatively universal accuracy; the latter is a function of rather complex and certainly arbitrary instruments—when these instruments are available.

The matter of *fixed factors*, if appropriate caution is not exercised, may further take one into the realms of the near-absurd. Shall we not correct all flours to a common protein content, either by adding gluten or by adding starch? We do not wish to cast reflections on the recent excellent work of Sandstedt, Jolitz, and Blish (1939) in which they report separating the starch from the gluten and subjecting these individually to study. Theirs is certainly a sound attack just as the one raised by our question above is unsound. The second pitfall to be avoided in using fixed factors, then, lies in fixing one factor at the expense of another possibly more important one.

The Role of Gas Production

As pointed out by many writers the conventional baking test produces a loaf the characteristics of which are a function of at least two distinct groups of effects; in the first we may place the rate of gas production and in the second all factors other than the rate of gas production. It is apparent that a simple method for separating the rate of gas production as a variable would then permit a far simpler interpretation of the baking test. This, too, has been the subject of much discussion. Concerning the techniques for accomplishing that separation, however, there is much disagreement. Perhaps the one most employed at the present time consists of proofing to constant height rather than to constant time.

We will first attempt to give analytic expression to the theoretical weakness of this technique, and then will consider the selection of a method which has indications of being superior. As a starting point we may estimate the volume V' of the molded dough after pan proof and immediately prior to entrance in the oven. It is equal to the sum of the volume of the dough at molding, A, and that proportion of the gas produced during proof which is retained.

Hence

$$V' = A + \int_{t_1}^{t_2} P_{ex} \left(\frac{R_P - R_L}{P_i} \right)_t dt, \qquad (1)$$

where t_1 represents the time of molding, t_2 the time at which pan proof is ended, R_P the rate of gas production, and R_L the rate of leakage at time, t. P_{ex} signifies the external atmospheric pressure and P_i the average pressure within the dough at this time.

Both R_L and P_i may be considered complex functions of the size and shape of the dough mass as well as of R_P and V'. The ratio P_{ex}/P_i may be neglected only insofar as the dough is made sufficiently small, for under this condition the relative dough surface increases, the total rate of leakage approaches R_P and as a consequence P_i approaches P_{ex}. We may tentatively assume, therefore, that the elimination of P_{ex}/P_i for 8.00-g. doughs is justified. The fact that gas-production data acquired from this size of aliquot show no response to those quantities of potassium bromate which are known to affect the physical properties of the dough may be considered as evidence. Such gas-production measurements may then be considered to determine R_P rather than P_{ex}/P_iR_P, particularly if such measurements are to be employed in interpretation of a baking test performed on a relatively larger dough. The rate of expansion of the dough [3] at time t is therefore represented by $R_P - R_L$ for small doughs and by $P_{ex}/P_i(R_P - R_L)$ for large doughs.

Rather than thinking in terms of size it is perhaps better to think in terms of relative free surface. It follows that if one wishes to remove R_P as a variable affecting the baking test, then neither proofing for a constant period of time nor proofing to a constant height is a suitable attack. For if one assumes that variations in A with variations of flour or variations of supplementary ingredients are negligible compared to the variations in the integral of equation No. 1, then the former method merely limits the range of the integral while permitting R_P and R_L and the integral to vary. The latter method removes the time limitations upon the integral in a fashion such that the integral always has a constant value, permitting nonetheless both R_P and R_L wide fields of variation.

This would at first sight seem unimportant. For here at least all doughs upon entering the oven apparently contain similar if not identical volumes of gas. It would seem then that the loaf volume would measure some average rate of leakage. But unfortunately this may be far from the truth, since at least during the first three or four minutes of baking (A.A.C.C. procedure) the dough undergoes expan-

[3] It is of interest to note that many workers, as for example Elion (1939), call the maximum value of the integral

$$\int_{t_1}^{t_2} P_{ex} \left(\frac{R_P - R_L}{P_i} \right)_t dt$$

the *gas-retaining capacity* or *retention*. It is not usually mentioned, however, that this characteristic is a function of gas production whether the rate of gas production is small or large, as well as it is of the rate of leakage. It is important that whereas R_P has clear-cut physical significance, R_L is itself dependent upon V' and hence upon R_P and is therefore of rather obscure physical significance. In fact, it may be concluded that the *gas-retaining capacity* can be of little value as a flour characteristic unless the behavior of R_P as a function of time (a factor in the sense of Landis and Frey) can be made common to all flours studied at the expense perhaps of varying an otherwise relatively unimportant ingredient or condition.

sion and both R_P and R_L during this interval may behave quite erratically. For example it has been our experience that many flours which possess large positive bromate responses often proof lower in the pan in the plus rather than in the minus dough; that is, the bromate response is demonstrated by oven expansion rather than by expansion in the pan. Since it can be shown that potassium bromate in the quantities normally used (0.001% based on flour) does not affect gas production, it would seem that the average rate of leakage, $\bar{R}_L$, during pan proof is greater for the plus dough, while the average rate of leakage, $\bar{R}_L$, during baking is less for the plus dough.

On the other hand, it may be that the plus dough has been so changed that greater force is required to produce a given amount of pan expansion, and that rather than $\bar{R}_L$ being greater, it is actually smaller, and the apparent lack of pan expansion is due to compression of the gas within the dough structure. Whatever the explanation, it remains that neither technique, fixed time, nor constant height of pan proof really separates gas production from gas leakage or from the baking test. Ideally, it remains to design a baking test which automatically maintains a common rate of gas production during pan proof and during the first five minutes, say of baking, independent of the supplementary ingredients. If this cannot be done then at least criteria may be attempted whereby appropriate legitimate corrections may be applied. The latter in general is the simpler attack.

Basic vs. Primitive vs. Commercial Formulas

Before proceeding it may be wise to define certain terms: *Basic ingredients* has been taken to mean flour, water, yeast, sugar, and salt. *Commercial ingredients* for the present purpose refers to flour, water, yeast, sugar, salt, milk, and shortening. The use of the description *primitive ingredients* refers to flour, water, and yeast. Any ingredient not included in the above definitions is classed as a *supplementary ingredient.*

In the study of flour, American cereal chemists have adopted the basic formula as one in which flour plays the prime part and which therefore permits the flour to display its characteristics under laboratory conditions. The problems involved in the study of supplementary ingredients, however, are different at least in scope. The supplementary ingredients may interact not only with the flour but as likely as not will interact with any or all of the commercial ingredients as well. Hence a commercial rather than a basic formula is indicated for work of this type. In addition, some supplementary ingredients, particularly insofar as gas production is concerned, may initiate different responses dependent upon whether the fermentation is principally

one of maltose or one of sucrose. This leads to the selection of a primitive formula as well as a commercial one; that is, we may be interested in how the supplementary ingredient affects gas production in the sponge stage (primitive formula), how it affects gas production in the dough stage (commercial or basic formula), and finally how, after consideration of effects upon gas production during proof and early baking, it affects the finished loaf.

Straight Dough vs. Sponge-Dough Process

If it is granted that supplementary ingredients may affect properties other than gas production, and may produce greater or less or even opposite effects depending upon their time of contact with the fermenting dough and if it is further granted that in the study of flour, characteristics other than those of gas production also vary with the age of the dough, then it follows that the sponge-dough procedure, far more readily than the straight dough, permits one to determine such effects.[4]

The work of Frey, Freilich, and Ekstedt (1937) on sponge doughs forms our basis for this statement. We quote: "It may therefore be concluded that after a minimum sponge fermentation of about 3½ to 4½ hours, depending on the temperature of the medium within which they are set, and using the type of flour and formula given above, laboratory sponges may be fermented within a wide range of time—up to 7 hours, and possibly more, and then produce bread of good quality." Our experimental findings will serve to amplify their observations and will verify the *a priori* judgment that this stability towards changes in sponge time is to be expected except under more or less unusual circumstances.

This tolerance will be shown to rest upon the fact that gas production during the dough stage of a properly conducted sponge-dough procedure is relatively independent of sponge time for a given flour after some minimum sponge time depending upon a predeterminable characteristic of that flour. In fact, it is evident even at this point that the matter of potential sugar levels is naturally solved by the sponge-dough technique—particularly if the sponge percentage is kept high relative to the dough percentage. The problem of common level

[4] That Shellenberger and Ziemke (1939) found the sponge-dough procedure less informative than the straight dough we cannot accept as a valid objection to the former technique. In the first place their formula included those ingredients "used by the average baker." Several objections to this procedure other than those already raised are evident: (1) In a test already suffering through lack of a standardized ingredient (yeast), other even less standardized ingredients (milk, shortening, and malt) are superimposed. (2) Yeast food, at times not sufficiently homogeneous in composition to escape notice by the commercial baker when used in relatively large quantities (a pound or more) is here used in an analytical test in the relatively small quantity of a gram or less. (3) Milk itself has a stabilizing effect upon at least certain flour responses as pointed out by Ofelt and Larmour (1940) and Eisenberg (1940). In the second place they employ a standard sponge or dough flour when testing dough and sponge flours respectively. Determining whether a flour is suited for sponge or dough use itself is one of the many objects of the baking test as we understand it, and hence the flour under consideration must not be masked by blending—certainly not in any method which is to serve as *basic*.

of gas-production rates for all flours, however, remains unsolved as is to be expected since important variables other than sugar level as yet are uncontrolled. Possibly thiamin (Schultz, Atkin, and Frey, 1937) and certainly amino nitrogen play their respective parts.

Experimental

This work as indicated in the title concerns itself particularly with the study of gas production, though in the present instance application of such data to the development of a baking test is attempted. Two formulas are selected as points of departure, one for the study of supplementary ingredients, another for the study of flour. For the latter purpose, in this preliminary probe, we employ the *basic* formula of the A.A.C.C.;[5] for the former we accept a commercial formula in which 4% of powdered skim milk (spray), 4% of hydrogenated cottonseed oil, 2.5% sucrose, and 1.0% sodium chloride (all based upon flour weight) are superimposed upon the *basic* formula. Absorption is kept constant at 60%[6] (15% moisture basis) for both sponge and dough, though tentatively 1% additional water is used for each percent of milk powder. Supplementary ingredients unless otherwise mentioned are incorporated in the sponge. Three percent of yeast *A* based upon sponge flour is used throughout. Thus an aliquot may be taken for the determination of the rate of gas production (primitive) in conformity with the procedure established in Part II of this series.

One modification of this procedure in which the preparation of the sponges is described in detail may be noted. Only one sponge is to be mixed each quarter hour, instead of two, but this in sufficient quantity to prepare a dough large enough for two 150.0-g. and two 8.00-g. aliquots. The former are to be employed in the baking test, the latter in the determination of the rate of gas production (dough stage) as a function of time.

The sponges are fermented in a thermostatically controlled proof box at 30.0 ± 0.1° C. for lengths of time as indicated in the experimental data. Doughs are mixed in a single-speed Bachmann mixer as follows: All soluble ingredients are dissolved in the prescribed amount of water. The flour and shortening are placed in the mixing bowl, whereupon the milk is taken up in the water and also added. The sponge is then superimposed and mixing proceeds for one minute.

[5] The acceptance of this formula by ourselves has been only tentative. Since the data of this paper have been acquired, we have been investigating a new formula which may be identified as the *reference formula*. This applies particularly to sponge-dough use and consists of 3% yeast based upon sponge flour (80% sponge), and 5% sucrose, 2% sodium chloride, and 60% absorption based upon total flour. This change is based upon two circumstances. First, the sugar and salt contents are hereby brought into correspondence with those of the commercial formula. Second, a sharply declining rate of gas production versus time curve in the dough stage is avoided.

[6] For those who may object to this technique it may be noted that either increases or decreases in absorption of at least 4% do not affect rate of gas production data tangibly. This is in agreement with the conclusion of Halton (1938) and with Heald (1932).

Twenty seconds are now taken for cleaning the bowl with the aid of a large spatula. Alternate mixing and cleaning are then continued in 40-second and 20-second steps, respectively, until the dough has received a total of three minutes of mixing. Aliquots for gas-production study are taken immediately and the remaining dough is permitted to rest for 25 minutes. It is then scaled and molded by means of a Model G Thompson Roll Molder. The molded dough is placed in the high-type aluminum pan and proofed for 55 minutes at 30.0°C. Baking is done at 230 ± 3°C. in a thermostatically controlled Despatch oven equipped with a rotating platform. Loaf volumes are measured to the nearest 5 ml. by displacement of rape seed.

Gas-Production Data

Since we have recently decided in favor of 80% sponges, and since all experimental work to be done by us in the future will be restricted to this condition, it is perhaps unfortunate that certain of the data immediately to be discussed were obtained via 50% sponges. But we

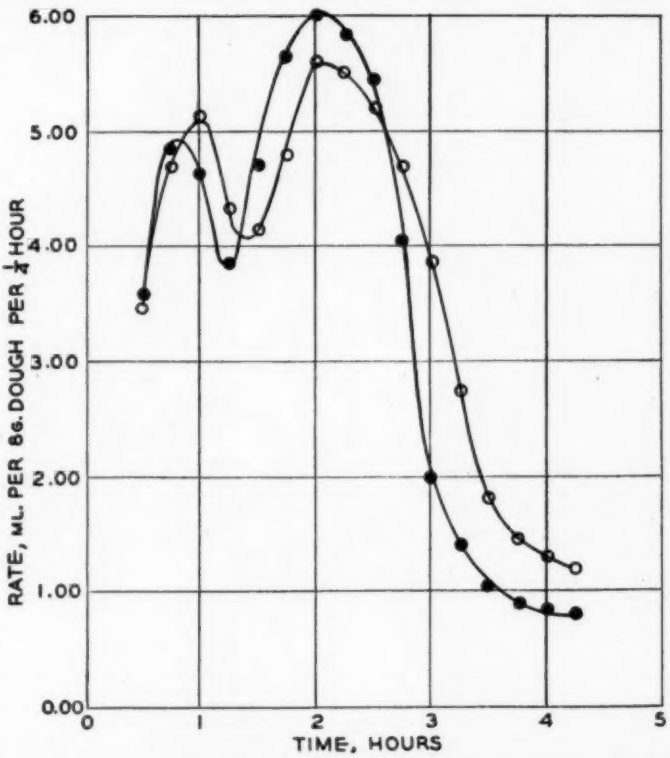

Fig. 1. Sponge curves for flour LS9c and flour LS11. The former is represented by closed circles and the latter by open circles.

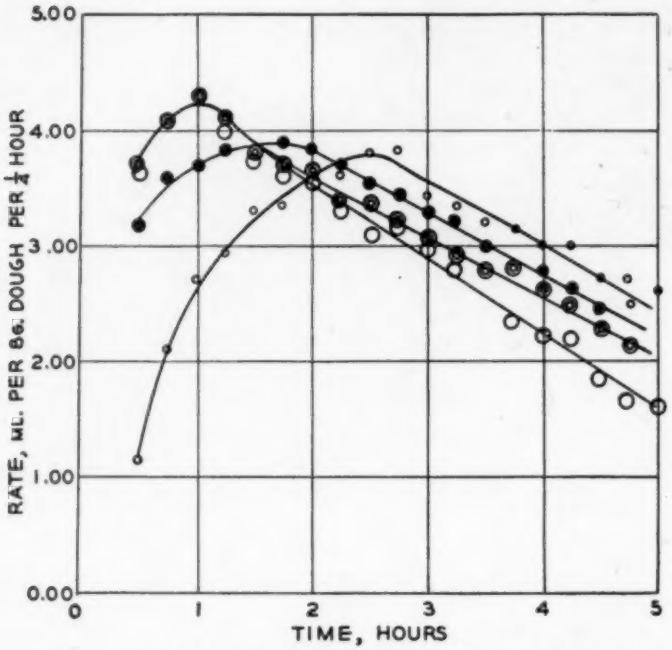

Fig. 2. Dough curves via basic formula, 50% sponge and flour LS9c for various sponge times. Small circles, no-time sponge; closed circles, 1 hour; double circles, 2 hours; and large circles, 3 hours of sponge time.

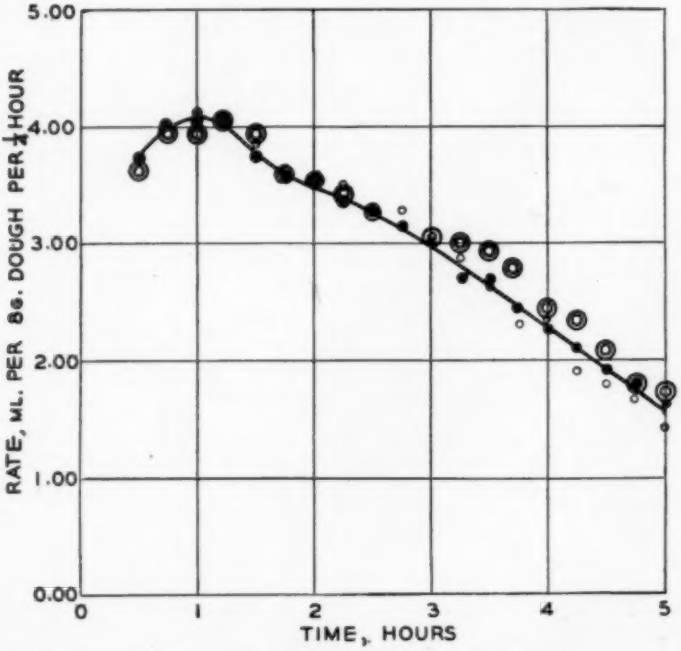

Fig. 3. Dough curves via basic formula, 50% sponge and flour LS9c for various sponge times. Closed circles, 3½ hours; open circles, 5 hours; and double circles, 5½ hours of sponge time.

think their presentation at this time is justified nevertheless as an indication of the generality of the principle to be drawn, namely, that the rate of gas production in the dough stage for any given set of ingredients and conditions is, after some minimum sponge time, relatively independent of the sponge time. All data other than those given in conjunction with simultaneously obtained baking data are corrected to standard pressure and temperature; those given in conjunction with the baking data are corrected only to standard temperature.

Basic formula—50% sponge—flour LS9c.—This flour, one intended for baker's sponge use, possesses 11.9% protein and 0.40% ash, and is here used both in sponge and in dough. Figure 1 represents the rate of gas production as a function of time during sponge fermentation.[7] The leveling off of the rate of gas production to a relatively linear decline of small slope after some 3½ hours is evident. This is in agreement with the findings of Sandstedt, Blish, Mecham, and Bode (1937). As pointed out by them, this very likely indicates complete consumption both of native and readily formed sugars. The persistence of gas production after this point is very likely due to the slow formation of additional sugars from nonsusceptible starch by an alpha-amylase-like enzyme. If this is true, it follows that all sponges taken after this time must possess a practically common sugar level. Hence all doughs mixed from sponges of 3½ hours or greater age with the flour under consideration should yield common rates of gas production vs. time curves.[8] This is experimentally established in Figures 2 and 3.

Basic formula 50% sponge—flour LS9c—0.05% NH_4Cl.—The group of dough curves obtained under these conditions and illustrated in Figures 4 and 5 serve as supporting evidence for our thesis. One interesting side issue is worthy of note. The work of Larmour and Bergsteinsson (1936) has already shown that there is no rate of gas-production response to ammonium chloride during the first 2 hours of fermentation under their conditions. We may qualify our agreements with their findings by a matter of some 30 minutes; that is, we have found ammonium chloride responses in straight dough procedures at about 1½ hours and longer. In the present instance one may note by comparing these figures with Figures 2 and 3, that the time at which the ammonium chloride response becomes evident is an inverse function of the sponge time, decreasing to zero at a sponge time of some 2½–3 hours.

Another pertinent point rests with the fact that the ammonium chloride peak seldom precedes the control peak. In fact, it usually

[7] Curves of this type will hereafter be referred to simply as *sponge curves*.
[8] Curves of this type will hereafter be referred to simply as *dough curves*.

follows it. This has been verified under various other conditions and with many other flours.

We may combine these two observations with a third, namely, that since more gas has been produced prior to the peaks in the presence of ammonium chloride than in its absence and since it can and will be shown at another time that the ammonium chloride effect is not tangibly associated with diastatic activity, contrary to the surmise of Larmour and Bergsteinsson (1936), there is less sugar remaining in the

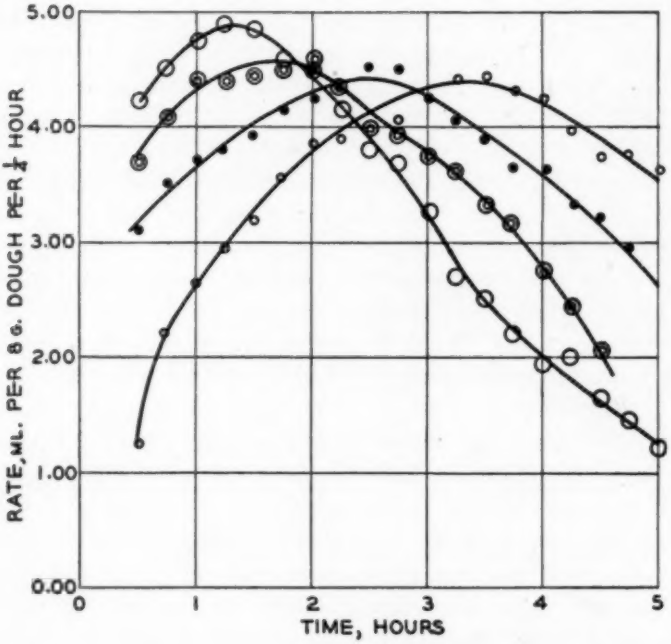

Fig. 4. Dough curves via basic formula, 50% sponge, 0.05% ammonium chloride, and flour LS9c for various sponge times. Small circles, no-time sponge; closed circles, 1 hour; double circles, 2 hours; and large circles, 3 hours of sponge time.

ammonium chloride dough than in the control dough at the time of their respective peaks. Nonetheless, the ammonium chloride peak is higher. These facts will have to be taken into consideration in any attempt to explain the ammonium chloride effect.

Commercial formula—80% sponge—flour LS11.—This flour is analytically akin to LS9c. It differs from that flour, however, in its sponge-curve characteristics as is evident from Figure 1. The leveling-off point occurs somewhat later at about 4 hours. Figures 6 and 7 represent the dough curves, doughs having been produced from sponges of varying age. It is evident that even the 27-hour dough curve is superimposible upon the 4-hour curve for the first 2 hours of dough

fermentation. At the 2-hour point in dough fermentation, however, according to the baking schedule already outlined, our loaf would have been out of the oven some 25 minutes.

The three preceding cases, then, may be considered proof of the initial argument, particularly since several dozen other isolated cases have been studied without unexpected disagreement. This restriction placed upon the general principle may occasionally manifest itself,

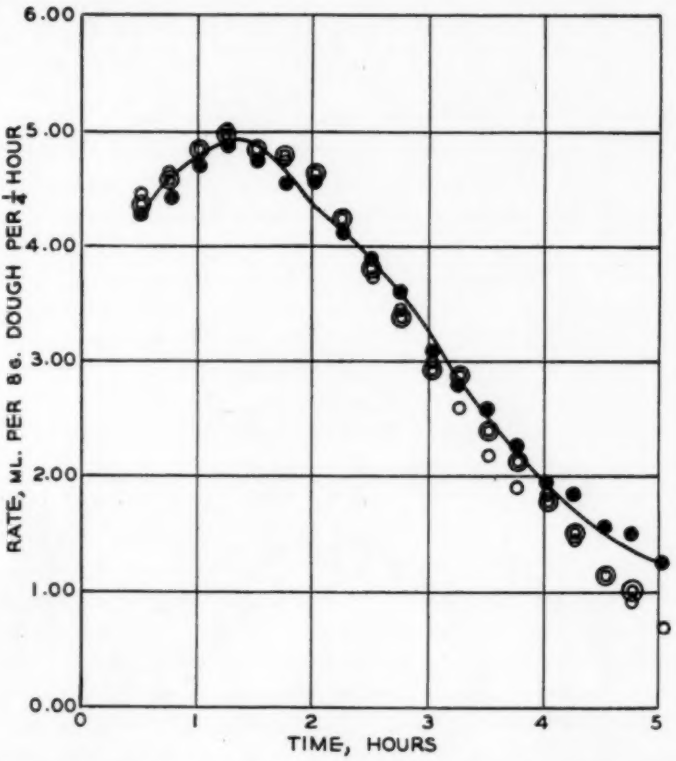

Fig. 5. Dough curves via basic formula, 50% sponge, 0.05% ammonium chloride, and flour LS9c for various sponge times. Closed circles, 3½ hours; open circles, 5 hours; and double circles, 5½ hours of sponge time.

either by a slight lowering or rising of the dough curve as the sponge time is increased beyond the minimum sponge time involved. For example, the presence of papain (in the order of 0.002%–0.004%) may indirectly stimulate a positive response very likely because of the induced progressive increase in amino nitrogen. A negative response of magnitude varying with the substrate may be explained by a differential in rate of inhibition or of destruction of zymase. Notwithstanding such minor fluctuations it certainly appears that if fermentation

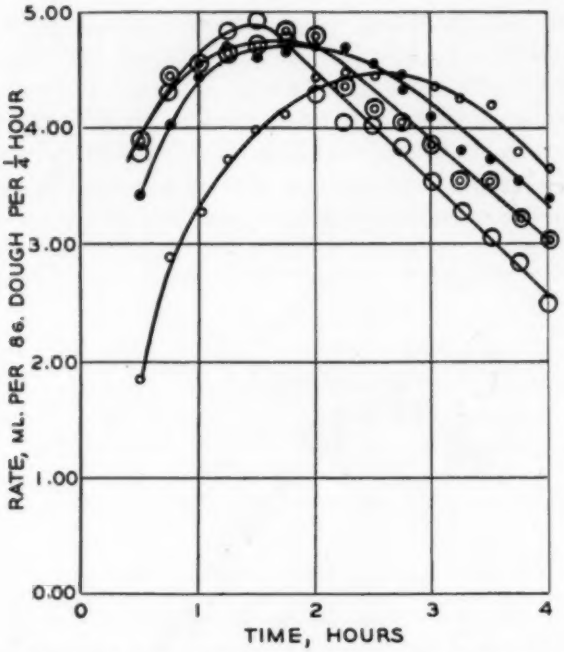

Fig. 6. Dough curves via commercial formula, 80% sponge and flour LS11 for various sponge times. Small circles, no-time sponge; closed circles, 1 hour; double circles, 2 hours; and large circles, 3 hours of sponge time.

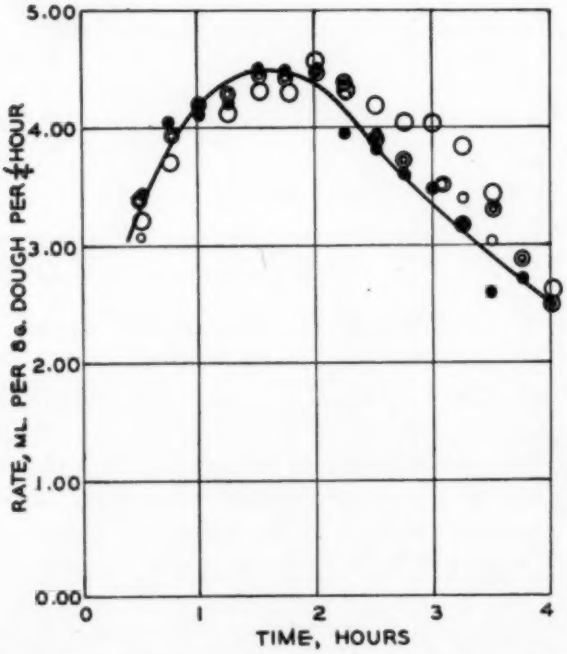

Fig. 7. Dough curves via commercial formula, 80% sponge and flour LS11 for various sponge times. Closed circles and solid line, 4 hours; small circles, 5 hours; double circles, 6 hours; and large circles, 27 hours of sponge fermentation.

time is a variable to be considered, the straight-dough cannot possibly compare in utility to the sponge-dough procedure.

Separation of Gas Production as Variable in Baking Test

One suggestion has already been given, namely, the use of an excess of maltose rather than sucrose plus about 0.07% ammonium chloride in the basic A.A.C.C. procedure and proofing during the third hour. Though this prove to be satisfactory for the purpose, we are not in a position at this time to discuss its application to the sponge-dough method. But it is the sponge-dough method which has been shown to be of more general utility. Hence we will consider two other attacks. The first will be the more direct and the more exact, but unfortunately somewhat less practical in application. The second may prove as exact as the baking test with which it is to be associated, if not more so, and therefore may be considered precise enough for the purpose.

The method of variable proof time.—This method is based on the assumption that small variations in dough time are of no significance except insofar as they affect gas production. We consider the assumption justified in view of the fact that 80% of the flour will already have received more than 3½ hours of fermentation in the sponge. Further, the constant factor of 150/8 relating gas-production data and baking data will be absorbed in any other constants to appear, and, though in no sense being neglected, need not prevent us from directly employing gas-production data obtained via 8.0-g. aliquots.

Two conditions should be satisfied in the proper elimination of gas production during proof as a variable: (1) gas production during proof must be common, and (2) the rate of gas production upon completion of proofing must also be common from flour to flour and supplementary ingredient to supplementary ingredient. Both of these conditions cannot in general be simultaneously fulfilled without requiring the dough time to undergo relatively large variations. Hence, one must here make his choice between fixing the factor of dough time or fixing the factor of the rate of gas production upon entrance to the oven. The former condition, however, is met simply by determining the dough curve prior to baking, selecting a standard interval of time from mixing of dough to entrance in oven, and computing the time at which molding must occur in order to permit an arbitrarily selected and standardized amount of gas to be produced during proofing. Or more simply, employ a standard dough time and proof to a common level of gas production as determined by simultaneous study of an aliquot.

Both conditions can at times be satisfied with the occasional sacrifice of fixed dough time by the following technique. Here the dough

curve must be obtained prior to baking. Further, besides standardizing the amount of gas to be produced one must also standardize the rate to be desired at the completion of proofing. For our purpose we standardize gas production during proof at 17.00 ml. and rate at entrance to oven at 3.75 ml. per quarter hour. Then from the dough

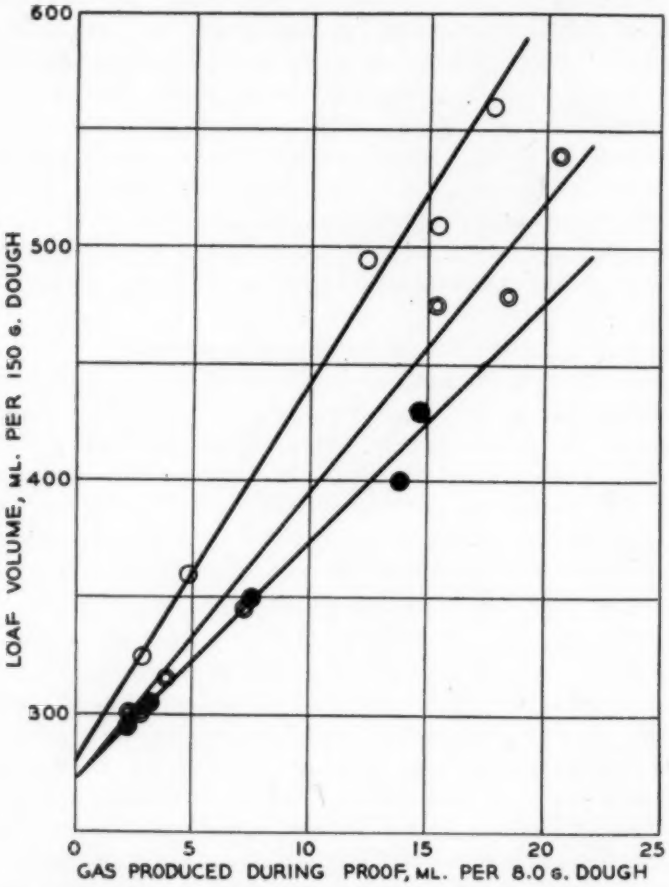

Fig. 8. Standard A.A.C.C. procedure, primitive formula, fermentation time variable in ½-hour steps beginning at 1 hour. Open circles, flour Lab3; closed circles, flour Lab2; and double circles, flour LS9c.

curves we determine the time required for the rate on its decline to reach 3.75 ml. per quarter hour. This time is to constitute the period from mixing of dough to entrance in the oven. The duration of proofing is calculated from the dough curve so that 17.00 ml. of gas is produced. For example consider the 4-hour curve in Figure 7. The required rate is reached in 2½ hours. It is evident that if molding were done at the 1-hour-and-29-minute point, 17.00 ml. of gas would

be produced in the 1-hour-and-1-minute interval between the two times.

As can be seen, this method is cumbersome and requires that complete gas-production data be available before the baking test is

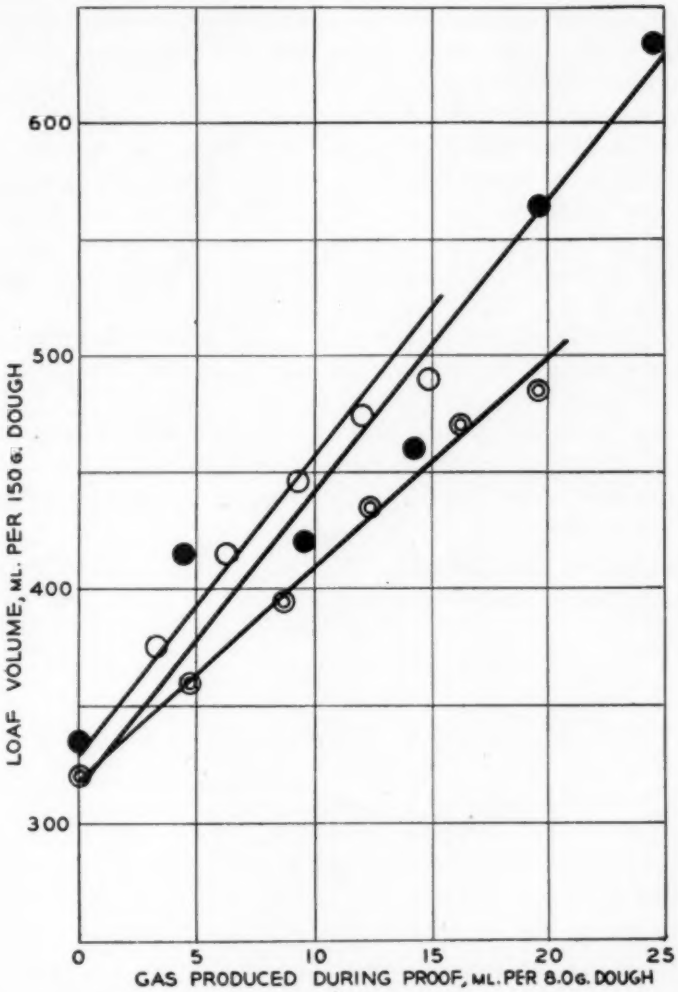

Fig. 9. Sponge-dough procedure, basic formula, 3½-hour sponges, proof time variable in ½-hour steps beginning at zero proof. Closed circles, flour Lab37; open circles, flour 7540; double circles, flour 101837.

attempted. Another objection rests with the fact that variable proof times are not in harmony with a simple schedule of procedure.

The method of constant proof time.—We do not here attempt to control gas production during proof; rather we determine the functional relationship between it and loaf volume. That is, we hope to

predict the loaf volume that would be obtained were 17.00 ml. of gas produced during proof from data acquired via a fixed time schedule. Hence, only loaf volumes and not other characteristics are to be separated from gas production, though we may here indicate that our findings concerning the variation of internal characteristics with moderate changes in proofing time are not such as to predict difficulties in interpretation. It is this technique which will be employed by us in future communications.

The theory of the method is based on the premise that loaf volume is a continuous function of gas produced during proof, notwithstanding the fact that an occasional point as determined may indicate discontinuity by deviating from the best continuous line through all observed points by more than the apparent experimental error of the baking test as estimated from replicate determinations at that time. This is justified at least in part by our repeated observation that two pairs of loaves prepared several hours apart often differed in average volume by 20 to 25 ml. though the volume spread between loaves in each pair was no greater than 5 or 10 ml.

In Figures 8 and 9 we present loaf volume as a function of gas produced during proof for six flours, the analytical characteristics of which are indicated in Table I. These figures consider the two possible

TABLE I

ANALYSES OF FLOURS STUDIED, CORRECTED TO 15% MOISTURE BASIS

Flour	Protein	Ash	Retention constant (average)
	%	%	
Lab2	9.5	0.48	7.0 [1]
Lab3	10.6	0.40	13.6 [1]
Lab37	16.7	0.84	11.2 [2]
LS9c	11.9	0.40	9.6 [1]
LS11	11.9	0.40	—
7540	8.2	0.38	14.9 [2]
101837	10.9	0.41	9.2 [2]

[1] Primitive formula.
[2] Basic formula.

ways of varying gas production during proof, namely, that of varying the rate of gas production and proofing for a constant time, or that of maintaining a relatively constant rate of gas production and varying the proof time. Under both of these conditions sensibly linear behavior is observed. The results of Figure 8, however, must be considered in part fortuitous since linearity can be expected under these circumstances only if the physical properties of the dough do not vary with fermentation time. That this in general is not true is evident upon consideration of unsound flours or those treated with potassium bro-

mate, proteolytic enzymes, or other agents that affect these physical properties in a manner depending upon the duration of fermentation. It seems, therefore, that the arbitrarily selected flours here employed do not fall into any of these categories; rather they must be considered sound flours, and one must conclude that the physical properties of such flours insofar as loaf volumes are concerned display excellent stability towards changes in fermentation time. This in fact has been corroborated by the sponge-dough method already described by preparing loaves from 3-hour and 13-hour and even 24-hour sponges without finding any significant changes in loaf volumes. This is exemplified in Table II.

TABLE II

LOAF VOLUME, GAS PRODUCED DURING PROOF, AND LOAF VOLUME CORRECTED TO 17.00 ML. OF GAS DURING PROOF FOR FLOUR LS9c AS A FUNCTION OF SPONGE TIME—COMMERCIAL FORMULA

Sponge time	Loaf volume	Gas during proof	$V_{st} = 320 + 17.00K$
hrs.	*ml. per 150 g. dough*	*ml. per 8 g. dough*	
3	515	14.70	545
5	530	14.20	570
13	500	13.40	550

The results of Figures 8 and 9 may therefore be expressed by the linear equation:

$$V = V_0 + K\bar{R}_P t = V_0 + KV_P \qquad (2)$$

in which V represents the loaf volume obtained after t quarter hours of proofing, V_0 represents loaf volume at either zero proof or zero rate of gas production during proof, and $\bar{R}_P$ the average rate of gas production during the proofing period. V_P therefore equals $\bar{R}_P t$, the volume of gas produced during proof. K may be called the *retention constant*. It is apparent that V depends upon gas production during proof and upon all dough characteristics other than gas production, whereas V_0 may be considered independent of the former and substantially independent of the latter. By substantially independent we do not imply the absence of causal relationship between V_0 and flour characteristics; rather we imply that this relationship may be neglected in comparison to the more significant connection of V and flour characteristics. This assumption may be expected to approach exactness as the removal of residual gas by molding approaches completeness. Hence it may be expected to hold more closely for mechanical than for hand molding.

The estimation of V_0 can be made either from plots such as those under discussion or by merely baking doughs immediately out of the

molder. Seventeen independent determinations under the conditions of zero proof of Figure 9 for five flours and both the straight-dough and the sponge-dough basic-formula procedures lead to $V_0 = 319 \pm 11$ ml. This value is some 40 ml. higher than that of the V_0 obtained from data acquired under the straight-dough, primitive-formula, constant-proof-time procedure of Figure 8. We will now attempt both to interpret this and give theoretical justification for equation No. 2.

We write:

$$V = v_0 + \frac{150}{8}\frac{T_i}{T_{st}}\frac{P_{ex}}{P_i}\left[\int_0^{t_P}(R_P - R_L)dt + \int_{t_P}^{t_s}(kR_P - R_L)dt\right] \quad (3)$$

in which v_0 represents the loaf volume that would be obtained after any period of proofing if both the rate of gas production during this time and during the three or four minutes from t_P, the time of entrance in oven, to t_s, the time of setting of the loaf, were zero.

It is here assumed that retention characteristics may be neglected and that responses due to water vapor and dissolved gases are constant and independent of flour characteristics. With high-compression mechanical molding, the additional response due to entrapped carbon dioxide and air may also be included in v_0. T_i and T_{st} respectively represent the average loaf temperature at t_s and the standard loaf temperature upon entrance in the oven (approximately 303°K.). Similarly, P_i and P_{ex} signify the average pressure within the loaf at t_s and the external atmospheric pressure respectively. The integral between the limits of 0 and t_P equals the volume of gas retained during proof, since R_P and R_L are taken as the rates of gas production and of leakage respectively in milliliters at T_{st} and P_{ex} per 8.0 g. dough per quarter hour. In like fashion, the second integral denotes the volume of gas retained under the same standard conditions in going from t_P to t_s. The unit of time, of course, is the quarter hour. k is the temperature coefficient of the rate of gas production; that is, it is the ratio of R_P at $\bar{\bar{T}}_i$ to that at T_{st}, $\bar{\bar{T}}_i$ being defined as an internal loaf temperature averaged not only through space but over the time interval t_P to t_s.

Equation No. 3 may be simplified as follows:

$$V = v_0 + \frac{150}{8}\frac{T_i}{T_{st}}\frac{P_{ex}}{P_i}[(\bar{R}_P - \bar{R}_L)t_P + (k\bar{\bar{R}}_P - \bar{\bar{R}}_L)(t_s - t_P)] \quad (4)$$

in which the single bars above the symbols represent an averaging over the time range 0 to t_P. Similarly the double bars above the indicated symbols represent an averaging of the variables concerned over the time range t_P to t_s.

We now make an assumption which as will be seen is justified by the experimental evidence of Figures 8 and 9; namely, that:

$$\bar{R}_L = K'(\bar{R}_P - \bar{R}_L) \tag{5}$$

and that:

$$\bar{\bar{R}}_L = C'(k\bar{\bar{R}}_P - \bar{\bar{R}}_L). \tag{6}$$

That is, we take the rate of leakage as being proportional to the rate of increase of gas within the dough mass. Therefore:

$$\bar{R}_L = \frac{K'\bar{R}_P}{1 + K'} \tag{7}$$

and:

$$\bar{\bar{R}}_L = \frac{C'k\bar{\bar{R}}_P}{1 + C'}, \tag{8}$$

hence:

$$(\bar{R}_P - \bar{R}_L) = \bar{R}_P\left(1 - \frac{K'}{1 + K'}\right) = K''\bar{R}_P \tag{9}$$

and:

$$(k\bar{\bar{R}}_P - \bar{\bar{R}}_L) = k\bar{\bar{R}}_P\left(1 - \frac{C'}{1 + C'}\right) = C''k\bar{\bar{R}}_P. \tag{10}$$

These relationships are inserted in equation No. 4 to yield:

$$V = v_0 + \frac{150}{8}\frac{T_i}{T_{st}}\frac{P_{ex}}{P_i}[(K''\bar{R}_P t_P) + C''k\bar{\bar{R}}_P(t_s - t_P)]. \tag{11}$$

The significance of the *retention constant* now becomes clear, for placing:

$$\frac{150}{8}\frac{T_i}{T_{st}}\frac{P_{ex}}{P_i}K'' = K \tag{12}$$

and:

$$\frac{150}{8}\frac{T_i}{T_{st}}\frac{P_{ex}}{P_i}C'' = C, \tag{13}$$

we obtain:

$$K = \frac{150}{8}\frac{T_i}{T_{st}}\frac{P_{ex}}{P_i}\left(\frac{\bar{R}_P - \bar{R}_L}{\bar{R}_P}\right). \tag{14}$$

Equation No. 11 may be simplified to:

$$V = v_0 + Ck\bar{\bar{R}}_P(t_s - t_P) + K\bar{R}_P t. \tag{15}$$

We need now only place:

$$V_0 = v_0 + Ck\bar{\bar{R}}_P(t_s - t_P) \tag{16}$$

and equation No. 2 has been deduced. Furthermore, the difference of 40 ml. between the V_0 estimated from Figure 8 and that from Figure 9 is explained merely by the lower rate of gas production in the

oven for the former case in the range of low loaf volumes. It is evident that, since the loaf-volume intercepts of Figure 8 must vary with the rate of gas production at entrance to oven, the relationship between V and V_P should certainly be curvilinear. But it is also evident that if one neglects the points at low values of V_P (equivalent under the fixed-time schedule employed to neglecting points at low R_P), then an intercept of 320 ml. serves as well for the remaining points as does an intercept of 280 ml. That is, the baking test, at least in our hands, is not sufficiently precise to demonstrate the curvilinearity.

TABLE III

LOAF VOLUMES, GAS PRODUCED DURING PROOF, RETENTION CONSTANTS CALCULATED BY EQUATION NO. 20, AND PREDICTED LOAF VOLUMES FOR THREE FLOURS—PRIMITIVE FORMULA, STRAIGHT-DOUGH PROCEDURE—AS A FUNCTION OF FERMENTATION TIME

Fermentation time (hrs.)	Loaf volume (V)	Proof gas (V_P)	K[1]	Loaf volume (calc.)	Difference from exp.
		FLOUR LAB2			
1	400	13.9	6.3	409	9
1½	430	14.7	7.6	417	13
2	350	7.5	7.5	346	4
2½	305	3.2	7.6	302	3
3	295	2.4	7.5	294	1
		Average	7.0 ± 0.7		±6
		FLOUR LAB3			
1	510	15.5	12.5	528	18
1½	560	17.9	13.2	568	8
2	495	12.5	15.0	478	17
2½	360	4.8	15.8	349	11
3	325	2.9	15.8	318	7
		Average	13.6 ± 1.0		±12
		FLOUR Ls9c			
1	480	18.45	8.4	502	22
1½	540	20.60	10.1	530	10
2	475	15.25	10.4	462	13
2½	345	7.35	7.2	363	18
3	315	3.65	9.3	316	1
3½	300	2.85	7.2	305	5
4	300	2.55	8.6	302	2
		Average	9.6 ± 0.8		±11

[1] Average values of K are computed only from data wherein V is greater than 400 ml. in order to avoid large percentage errors arising from low volumes.

An interesting consequence of equation No. 15 lies in the possibility of determining at least the order of magnitude of k, the temperature coefficient of gas production from baking-test and gas-production data during proof. To do this, we first assume that C does not differ so far from K that one may not be replaced by the other. We may further take $(t_s - t_P)$ approximately equal to 3.5/15 quarter hour.

In addition $\bar{R}_P$ may as a first approximation be placed equal to V_P/t_P in which $V_P = \bar{R}_P t_P$. Also, for the data of Figure 8, $t_P = 55/15$ quarter hours. Hence equation No. 15 may be rewritten:

$$V = v_0 + \frac{3.5}{55} KkV_P + KV_P. \qquad (17)$$

Upon consideration of the open circles of Figure 8, we find $V = 560$ ml. for $V_P = 17.8$ ml. For this relatively large value of V_P we take $V_0 = 320$ ml. and calculate $K = (560 - 320)/17.8 = 13.5$. For this

TABLE IV

LOAF VOLUMES, GAS PRODUCED DURING PROOF, RETENTION CONSTANTS CALCULATED BY EQUATION NO. 20, AND PREDICTED LOAF VOLUMES FOR THREE FLOURS—BASIC FORMULA, SPONGE-DOUGH PROCEDURE—AS A FUNCTION OF PROOF TIME

Proof time (hrs.)	Loaf volume (V)	Proof gas (V_P)	K	Loaf volume (calc.)	Difference from exp.
		FLOUR LAB37			
0	335	0.00	—	325	10
¼	415	4.50	21.1 [1]	370	45 [1]
½	420	9.65	10.1	431	11
¾	460	14.35	9.6	484	24
1	565	19.65	12.3	544	11
1¼	635	24.65	12.6	600	35
		Average	11.2 ± 13		±18
		FLOUR 7540			
0	320	0.00	—	305	15
¼	375	3.30	20.9	355	20
½	415	6.25	17.6	398	17
¾	445	9.40	14.9	445	0
1	475	12.05	14.3	483	8
1¼	490	14.90	12.6	525	35
		Average	14.9 ± 1.4		±16
		FLOUR 101837			
0	320	0.00	—	315	5
¼	360	4.50	8.9	361	1
½	395	8.75	8.8	398	3
¾	435	12.55	9.5	431	4
1	470	16.35	9.5	465	5
1¼	485	19.70	8.7	494	9
		Average	9.2 ± 0.4		± 5

[1] Eliminated from average.

same flour at $V = 325$ ml., $V_P = 3.0$ ml. For this relatively small value of V_P, we take $V_0 = 280$ ml. and calculate $K = (325 - 280)/3.0 = 15.0$. Hence, 14.3 serves as an average estimate of K for the flour under consideration. But:

$$\left(\frac{3.5}{55}\right)(14.3)(17.8)k - \left(\frac{3.5}{55}\right)(14.3)(3.0)k = 40.$$

We here find that the temperature coefficient of gas production, in going from the standard temperature of 303°K. to an internal loaf temperature averaged not only through the dough mass but over the time interval between entrance in oven and setting lies in the vicinity of 3.0. That this value is completely rational is proved by estimating k by other means. For example, Bailey and Munz (1938) have shown that the temperature of setting lies between 50°C. and 60°C. Though their data are not strictly applicable to our conditions of working, we may very likely with less crude assumptions than have already been made take 55°C. as a tentative value. That is, the loaf temperature increases some 25°C. from the time of entrance to oven to the time of setting. Half of this value, 12.5°C., may be considered the average rise, wherein averaging is done over time. Hence, we must calculate the temperature coefficient for the range 303°K. to 316°K.

But:

$$\log_e k = \frac{E(316 - 303)}{R(316)(303)} \tag{18}$$

in which k is the desired temperature coefficient, R is the gas constant in calories per degree, and E is the energy of activation. 11,400 calories has been indicated as an average value of the energy of activation for enzymatic reactions.[9] We find upon calculation that $k = 2.17$. This agreement, if not accidental, is certainly remarkable.

Therefore, in view of the fact that V_0 varies only about 40 ml. and that variations in C and K affect this value in a secondary manner as compared to the effect of K upon the remaining terms of equation No. 15, we may take $C = 15$ and rewrite equation No. 15 for the 55-minute proof period:

$$V = v_0 + 3.0V_P + KV_P \tag{19}$$

in which $v_0 + 3.0V_P = V_0$. But we may take $V_0 = 280$ for low values of V_P, namely about 3.0 ml. Therefore we may assume v_0 to be in the neighborhood of 270 ml. We have finally:

$$V = (270 + 3.0V_P) + KV_P \tag{20}$$

or for the sponge-dough procedure, in which V_P generally lies in the range 12 ml. to 20 ml.:

$$V = 320 + KV_P \tag{21}$$

with a maximum error in V_0 of about 10 ml. In Tables III and IV are given the pertinent data of Figures 8 and 9 respectively with loaf volumes calculated by equation No. 20. In applying this equation to

[9] See page 230 of Respiratory Enzymes by the University of Wisconsin Biochemists, 1939—Burgess Publishing Company, Minneapolis, Minn.

the data acquired with variable proof time, it is obvious that V_P in parentheses must be calculated to a 55-minute basis, while V_P outside the parentheses must be the value determined for the given proof time.

One may here indicate that whereas V_0 and V may be expected to vary with different operators and with different equipment, K should prove relatively independent of such factors. Hence if V_0 and V_P are standardized at say 320 ml. and 17.00 ml., respectively, calculated loaf volumes obtained by different workers upon the same ingredients may well show more agreement than heretofore has been possible. That is, each worker first is to obtain his own V_0. He will then determine V and V_P for a given flour and calculate K by equation No. 20. A new standard V_{st} may be calculated by means of:

$$V_{st} = 320 + 17.00K. \tag{22}$$

Loaf Volume at Standard Gas Production

From Table I it is seen that no correlation seems to exist between K and protein content. Though variations in gas production during proof are eliminated, it appears nevertheless that loaf volume remains a function of more than one variable. This is demonstrated more explicitly by equation No. 14 where we find K and therefore V_{st} to be a function of the independent flour variables $\bar{R}_P$, $\bar{R}_L$ and P_i. Loaf volume measures a composite effect, and for the moment it is only through experience and strained interpretive processes in which dough and loaf characteristics serve as guides that loaf volumes may be taken to measure flour utility or *strength*. That fairly high correlation coefficients between loaf volume and protein content have been found in the past can be explained at least in part by the data of Tables I, III, and IV. It is seen that gas production during proof at corresponding times for corresponding conditions is a more definite function of protein content than is either K or V_{st}.

In Table V are recorded the maximum values of V_P obtained for a given flour and its protein content. The correlation between these

TABLE V

MAXIMUM VALUES OF V_P AS A FUNCTION OF PROTEIN CONTENT

Condition	Flour	Protein	Gas during proof
			ml.
Straight-dough, primitive formula, variable fermentation time. Proof time constant.	Lab2	9.5	14.7
	Lab3	10.6	17.9
	LS9c	11.9	20.6
Sponge-dough, basic formula, 3½-hr. sponge time. Proof time variable.	7540	8.2	14.90
	101837	10.9	19.70
	Lab37	16.7	24.65

variables becomes even more evident by study of Figure 10 in which one is plotted against the other for some fifteen flours. Several comments concerning the data of this figure are in order. First there was no observable relationship between 4-hour gas productions (primitive

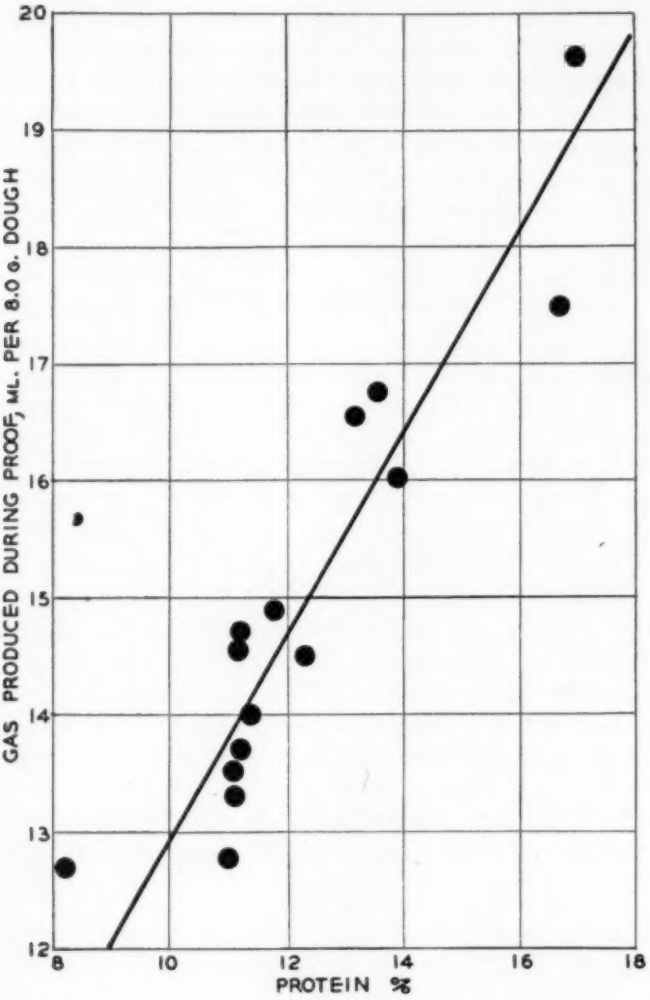

Fig. 10. Standard A.A.C.C. procedure, basic formula. Gas production during proof as a function of protein content.

formula) and protein content. Second, the variations in gas production during proof for these flours may be explained by four different hypotheses: (1) variations in thiamin, (2) variations in the *Z* factor of von Euler, (3) variations in the *M* factor of Blish and Sandstedt, or

(4) variations in amino nitrogen. Of these four, one can more readily visualize a correlation between amino nitrogen and protein content.

The problem of flour *strength* or that of gluten *quality* thus resolves itself into the interpretation of the relative significance of P_i and $\bar{R}_L$. Measurements of so-called *retention capacities* obviously cannot separate these factors; at best when taken in conjunction with gas-production data they may measure some average value of $P_{cz}/P_i\bar{R}_L$. One must also realize that while P_i may not in general be expected to differ greatly from P_{cz}, $\bar{R}_L$ itself is very likely a sensitive function of P_i. Therefore slight differences in P_i may prove of great importance in the proper interpretation of V_{st}. Furthermore, it seems likely that P_i may be a relatively simple function of the amount of force required to extend a unit block of dough a unit distance. It is not unlikely, therefore, that properly conducted extensometric measurements might ultimately lead to the desired separation of these dependent variables.

In conclusion, we may point out a field of at least qualitative utility in the relationships that have been derived. We have shown that both the retention constant and the standardized loaf volume are functions of the rate of leakage and of the internal pressure. For a given V_P, K, or V_{st} must evidently increase with decrease in R_L or decrease in P_i. We may for example apply these considerations to a flour possessing a positive potassium bromate response. Mere familiarity with the general effect of potassium bromate on dough characteristics is sufficient to indicate an increase in P_i. Hence, in order to obtain a positive volume response, it is evident that $\bar{R}_L$ must undergo a greater decrease than is apparent from loaf volume alone. Similarly, it can be shown that positive volume responses to malt preparations are generally greater than can be expected from only increases in gas production during proofing. Here we may qualitatively conclude that the increase in K or V_{st} is due primarily to a decrease in P_i rather than to a decrease in $\bar{R}_L$. It follows that a large loaf volume may at times be an indication of weakness as well as of strength. We have observed instances of this in the study of certain supplementary ingredients which, though almost invariably producing a positive volume response under usual laboratory conditions, produced a distinct negative response under commercial conditions of pound and a half loaves and forced steam in the oven.

Summary

Criteria for the design of a baking test to be used in the study of flour and supplementary ingredients are discussed. With these as a basis a sponge-dough procedure and primitive, basic, and commercial formulas are selected. Several methods for the separation of gas

production as a variable are described. One of these is advocated as particularly practical in application and worthy of continued study. It is shown, however, that loaf volumes obtained even under such conditions must be subjected to interpretation by an experienced worker before being of practical utility. Such loaf volumes remain a function of at least two principal variables, the rate of leakage of gas and the gas pressure developed within the dough. These variables may perhaps be separated one from the other by extensometric measurements.

Acknowledgment

This writer can think of no more appropriate place in which to express his feelings of gratitude to E. E. Werner. It was Dr. Werner who introduced him to the field of cereal chemistry. Without much mental stimulation and prodding, it is more than likely that the present work would never have been attempted.

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THE EFFECT OF LOW TEMPERATURE IN PREVENTING DAMAGE TO WHEAT STORED WITH HIGH MOISTURE CONTENT[1]

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It was shown by Swanson and Fenton (1932) that the fundamental cause of damage to wheat stored in farm bins is high moisture. This will favor growth of molds, and their biological activities as well as those of the wheat will generate heat. Since increase in temperature will also increase these activities, the process is self-accelerating and, if not stopped, will proceed until enough heat is generated to cause serious damage to the qualities of the wheat. Thus, while heat is the direct cause of the damage, the real cause was the high moisture content at the time of storage.

[1] Contribution No. 70, Department of Milling Industry.

That wheat may be stored 11 years in a farm bin without heating, and consequently remain undamaged, was shown by A. F. Swanson (1939). The moisture content of this wheat was 11% at the time of removal from the bin and had probably never been higher than 12% since it was combined in northwest Kansas when the weather was dry. The milling and baking tests revealed no apparent damage and some of the seed produced a stand equal to that from new seed. The climate is cooler and dryer in northwest Kansas than further east. A small sample of wheat stored for about 20 years in the loft of a granary near Junction City, Kansas, was dead and the volume of the baked loaf was 1140 cc. as compared with 2090 cc. for the check (Swanson, 1938). The longer time was probably a factor, but the higher temperature was no doubt the principal factor causing this damage.

In a previous publication (Swanson, 1934) it was shown that damage resulted most rapidly in samples stored in the laboratory during the summer, less rapidly when stored at about 60° F., and least rapidly when stored outdoors in the winter. It was also shown that the access of air was an important factor in mold development and also in the development of rancidity or acidity in the wheat fat. This is estimated by determining the mg. of KOH neutralized per gram of fat which is obtained by extracting a ground portion of wheat with ether. This development of acidity in the fat did not take place unless the conditions were such that mold developed. Serious damage did take place in the absence of mold, but this did not show itself in increased fat acidity.

The object of the present investigations was to confirm some of the previous findings as well as to get additional information, particularly on the effect of low temperature. Since the effects of low temperatures cannot be determined except in conjunction with other factors, variation in the amount of moisture, air access, and duration of time were also included. These experiments extended over two seasons, 1938–39 and 1939–40, and wheat from each season's harvest was used. The previous work had shown (Swanson, 1934) that it made but little difference whether wheat was used which was high in moisture because of being cut before complete desiccation had taken place, or whether water was added to wheat which had once been dry. It was the amount of moisture in connection with the high temperature which determined the extent of damage.

Experiments in 1938–39

Decrease in viability.—Wheat was placed in a number of 4-ounce glass-stoppered bottles. Half the number were placed in the laboratory and half in a room at 41° F. At various intervals these were

tested for viability. The most significant figures are given in Table I. There was no decrease in viability in the samples stored at 41° F. after 21 weeks, even when the moisture content was 20%. When stored in the laboratory the viability of the 14% moisture wheat had notably

TABLE I

EFFECT OF MOISTURE AND TEMPERATURE ON THE RATE OF DECREASE IN VIABILITY

Moisture	Laboratory		Stored at 41° F.	
	Weeks old	Germination	Weeks old	Germination
%		%		%
10	18	92	18	91
12	18	94	18	92
14	18	51	18	93
16	9	0	21	91
18	6	1	21	88
20	6	0	21	90

decreased at the end of 18 weeks and those with higher moistures were dead at the end of 6 and 9 weeks. This clearly indicates the efficacy of the lower temperature in preserving viability of wheat. As will be shown later, a high percentage of viability indicates that the wheat has suffered no damage to its milling and baking qualities.

TABLE II

FLOUR YIELDS AND ASH CONTENT FROM SAMPLES STORED AT VARIOUS MOISTURE CONTENTS IN THE LABORATORY AND AT 41° F.

Moisture during storage	Laboratory temperature		Cold room 41° F.	
	Flour yield	Ash [1]	Flour yield	Ash [1]
%	%	%	%	%
Check [2]	75.3	0.41	77.7	0.40
10	75.4	0.41	76.0	0.40
12	76.2	0.42	76.8	0.40
14	78.5	0.44	75.8	0.39
16	77.2	0.44	77.0	0.41
18	78.9	0.48	77.2	0.42
20	78.9	0.51	77.5	0.43

[1] Calculated on the 15% moisture basis.
[2] The checks in this and following tables were from the original lot of wheat used in these experiments and were stored in tin cans with slip-on covers alongside each group of bottles.

Effects of temperature and moisture on milling and baking qualities. —To determine the effect of temperature and moisture on the milling and baking qualities 1800-g. portions of wheat were placed in gallon bottles and amounts of water added which were required to provide samples, respectively, of 10, 12, 14, 16, 18, and 20% moisture. There

were two lots of bottles. One lot was stored in the laboratory and another lot was stored in the room kept at 41° F. The storage period was about seven months. To get the samples uniformly dry at the end of the storage period, the wheat was emptied from the bottles into shallow paper boxes and exposed until air-dry, which was known by comparing the weights of the higher moisture samples with the lower. The milling was done on the Buhler mill. The flour yields and the ash content on a 15% moisture basis of the straight flours are given in Table II. The flour yields indicate the percentage obtained from a weighed amount of cleaned wheat and have thus a comparative value among the samples. The flour yields were large without an unduly high ash. In the laboratory-stored samples, however, there was a gradual increase in ash content parallel with the higher moistures during storage, showing some deterioration in milling properties.

The flours were baked after they had been stored in the mill room for about six weeks. Two different formulas were used:

Formula A 2% yeast, 1.75% salt, 6% sugar, 3% shortening

Formula B 2% yeast, 1.75% salt, 6% sugar, 3% shortening, 6% dry milk solids, 3 mg. potassium bromate.

The absorption on the existing moisture basis and the mixing time were optimum as determined by observation. Doughs were made from 200 g. of flour, divided into equal parts and fermented at 86° F., 105 minutes to first punch, 50 minutes to second punch, 25 minutes to third punch when the doughs were passed between the rollers, molded in the Thompson molder and formed. The proof was for 55 minutes at 86° F. The baking was done in a Despatch rotary oven. The loaf volumes were the averages of duplicate loaves. One set of loaves was used for scoring and one set for photographing.

The results of the baking tests are given in Table III.[2] The flour moistures were uniform among each set of the samples. That is, the flours from the wheats which had had the higher moisture percentages were no higher than those which had had the lower percentages during storage. The variation within each group of samples was only 0.3%; however, the average for the laboratory-stored samples was 12.54 and for the samples stored at 41° F. it was 13.84. Why the flours from the wheats stored at 41° F. should average over 1% higher in moisture than those stored at laboratory temperature was not apparent. The

[2] Credit is due Mr. C. W. Ofelt, American Dry Milk Institute Fellow, 1938–39, for making the baking tests.

percentages of absorption were lowest in the samples stored with the highest moisture, the damage being thus reflected in loss of water-holding capacity.

The data in Table III show that the deterioration started with 16% moisture in the laboratory-stored samples, while in the samples stored in the cold room there was no deterioration until the moisture of the wheat during storage was 20%, and then it was slight. In fact the samples having 18% moisture stored in the cold room had as large a volume and as high a crumb score as any of the loaves.

TABLE III

BAKING RESULTS ON FLOURS FROM WHEATS STORED AT VARYING MOISTURE CONTENT IN THE LABORATORY AND AT 41° F.

Moisture during storage	Laboratory				41° F.		
	Absorp.	Loaf vol.	Crumb score	Color	Absorp.	Loaf vol.	Crumb score
%	%	cc.			%	cc.	
				FORMULA A			
Check	61	615	64	Good	60	615	64
10	61	600	57	"	60	605	60
12	62	615	58	"	60	610	59
14	62	630	57	"	60	635	59
16	59	615	50	"	60	618	59
18	55	445	30	Muddy br.	59	658	78
20	52	335	10	" "	55	603	45
				FORMULA B			
Check	61	848	88	Good	60	798	94
10	61	795	87	"	60	815	85
12	62	785	88	"	60	798	89
14	62	770	88	"	60	830	89
16	59	570	40	Sl. brown	60	823	89
18	55	403	15	Muddy br.	59	820	94
20	52	295	10	" "	55	698	90

The addition of bromate and dry-milk solids in formula *B* greatly increased the loaf volumes and the crumb scores. The *B* formula served even better than formula *A* to differentiate between the damaged and undamaged flours. The cut sections of the loaves obtained from formula *A* are given in Figure 1 and for formula *B* in Figure 2. The numbers on the loaves indicate the moisture contents at which the wheats were stored. The upper rows are from the cold-storage samples and the lower rows from the laboratory-stored samples. The greater amount of damage from the higher moistures of the laboratory-stored samples is very evident in comparison with the samples stored in the cold room.

One difference between the wheat is these bottle samples and wheat in storage bins is that in the bottles the heat does not accumulate and

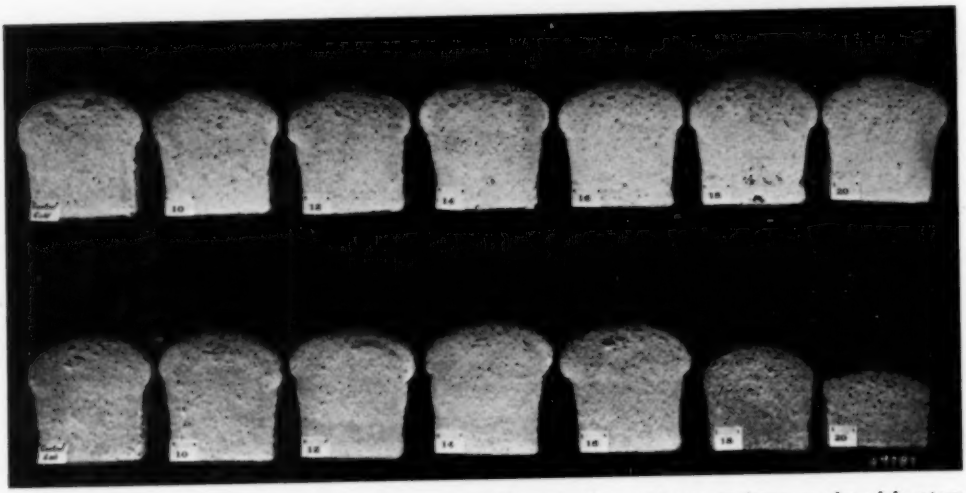

Fig. 1. Loaves baked with formula *A*. Loaves in upper row are from cold storage, lower row from laboratory storage. First loaves in each row are the checks; the numbers on the loaves indicate the moisture percentage of the wheat during storage.

Fig. 2. Loaves baked with formula *B*. Loaves in upper row are from cold storage, lower row from laboratory storage. First loaves in each row are the checks; the numbers on the loaves indicate the moisture percentages of the wheat while in storage.

hence the temperature of the wheat is very near that of the room. In a bin the heat accumulates and hence the temperature will be much higher than that of the surrounding air. This is probably the reason for the much smaller damage in the 16% and higher moisture samples stored in the laboratory as compared with what would have been expected in a bin at these moistures.

Experiments in 1939–40

Besides temperature and moisture, the factors of air supply and duration of time were also included during 1939–40. The containers were gallon bottles as before except for the check samples which were stored in tin cans. The same range of moistures was used as before except that 15% moisture was also used because the critical range in bins has been found to be between 14% and 16% (Swanson and Fenton, 1933). There were two groups of bottles and three lots in each group, both for the laboratory and the cold room. One group was sealed so the wheat would be under anaerobic conditions after respiration had consumed the oxygen in the interkernel air space. The other group of bottles were closed with a one-hole rubber stopper in which was placed a wad of cotton. This would admit a limited air supply such as occurs in a deep bin. The general plan was to test one lot after three months, the second lot after six months, and the third lot after nine months.

Tenmarq wheat from the Agronomy Farm was used. This wheat had been exposed to several rains after it was ripe and hence had undergone a certain amount of weathering. The test weight was 57.9 and the moisture as received 13.3%. It was therefore necessary to air-dry a portion of this wheat so as to have low enough moisture for the 12% samples as well as for the checks. The experiment was started the latter part of July, 1939. The first lot of bottles was opened and tested the last part of October, 1939; the second lot, the last part of January, 1940; and the third lot the latter part of April, 1940.

The tests made at the end of each period, aside from check weighings, were the following: examination for soundness as revealed by mold, mustiness, or odor; test weights on the wet, air-dry, and scoured samples; specific gravity; proximate viability. Milling and baking tests were made only on the three and six months samples as the nine months samples were accidentally destroyed just before milling.

Results obtained.—The examination for soundness was made by visual inspection and smelling. The results of these examinations are given in Table IV. When air had access the unsoundness took the form of mold or mustiness and when it did not have access it took the form of a sour odor, and in a few cases this seemed sweetish. An

attempt to measure by titration the amount of sourness in the samples which had the sour odor gave erratic results. The slight mustiness which was noted at the end of three months in the two sealed samples, both the laboratory and cold stored, may have been the beginning of the process which resulted in the condition designated by "sour odor." Time is a factor in the development of this condition. At the end of nine months it was noted even with 15% and 16% moisture. Thus sealing and cold storage did not prevent the development of some of

TABLE IV

EXAMINATION FOR SOUNDNESS

Sample description [1]	3 months	6 months	9 months
c-check	Sound	Sound	Sound
c-air-12	"	"	"
c-air-14	"	"	"
c-air-15	"	"	"
c-air-16	"	"	"
c-air-18	Musty	Sl. sour odor	Musty
c-air-20	Some mold	Sl. moldy	"
c-sld-12	Sound	Sound	Sound
c-sld-14	"	"	"
c-sld-15	"	"	Sour odor
c-sld-16	"	"	" "
c-sld-18	"	Sl. sour odor	" "
c-sld-20	Sl. musty	Sweet	" "
1-air-check	Sound	Sound	Weevil eaten
1-air-12	Sound	Sound	Sound
1-air-14	"	"	"
1-air-15	Sl. musty	Sl. musty	Sl. musty
1-air-16	Musty	Musty	Very moldy
1-air-18	Very moldy	Very moldy	Very moldy
1-sld-12	Sound	Sound	Sound
1-sld-14	"	"	"
1-sld-15	"	"	"
1-sld-16	"	Sw. odor	Sour odor
1-sld-18	Sl. musty	Sweet-sour	Very sour

[1] Abbreviations: c = cold storage, sld = sealed, l = laboratory. Figures refer to moisture content while in storage.

those characteristics which are associated with damage. Such tests as these which are based on personal judgment are subject to considerable variation; however, the odor test, as will appear later, is more sensitive than several other tests.

The test weights were taken as soon as the wheat samples were emptied from the bottles, after they were air-dried, and also after they were scoured. The weights of the samples showed that all had dried to nearly 10% moisture and hence moisture variation was not a factor.

In studying the figures obtained it was noted that the length of storage did not have much influence on changes in test weights and, hence, the figures obtained from the three, six, and nine months storage were averaged for each moisture condition. These average test weights are given in Table V. In studying these data, it should be remembered that test-weight figures have considerable experimental errors regardless of the care taken in performing the test; hence only definite trends or larger differences have any meaning.

TABLE V

TEST WEIGHT AS INFLUENCED BY STORAGE CONDITIONS

Cold—41° F.				Laboratory			
Description of sample	Wet	Air dried	Scoured	Description of sample	Wet	Air dried	Scoured
Air-check	58.1	58.1	60.6	Air-check	57.9	57.6	60.5
Air-12	57.3	57.1	60.4	Air-12	57.0	57.0	60.4
Air-14	57.5	57.3	60.7	Air-14	57.2	57.4	60.5
Air-15	56.3	56.6	60.3	Air-15	54.4	54.8	59.9
Air-16	56.3	56.8	60 2	Air-16	53.3	54.0	59.1
Air-18	53.4	55.1	59.8	Air-18	50.8	51.9	57.8
Air-20	52.3	54.1	58.9	—	—	—	—
Sealed-12	57.4	57.3	60.7	Sealed-12	57.3	56.9	60.6
Sealed-14	57.6	56.8	60.5	Sealed-14	57.6	56.6	60.2
Sealed-15	56.5	56.6	60.2	Sealed-15	55.7	56.4	60.3
Sealed-16	56.1	56.3	60.1	Sealed-16	54.8	56.0	59.9
Sealed-18	54.1	55.6	59.6	Sealed-18	52.9	55.3	59.4
Sealed-20	52.5	54.8	58.9	—	—	—	—

The samples stored in the cold decreased progressively in the test weights made before drying to the extent of nearly 5 pounds between the 12% and 20% moisture levels. After drying the decrease was nearly 3 pounds. That is, the increase in moisture content by addition of water to wheat will decrease the test weight in relation to the amount of water added, and this decrease will persist after redrying, but to a lesser degree. The amount of decrease in test weight due to wetting and redrying obtained in this experiment was not as great as in a former trial (Swanson, 1939). This was probably due to the partial weathering of this wheat before the experimental wetting. The test weights of the scoured samples were in all cases considerably larger than the unscoured because of the greater smoothness of the outer surface which resulted from the removal of the loose bran layers and which in turn would cause a closer packing. The decreases in test weight of the scoured samples were small with the progressive increase in moisture until the wetting had been 18% and 20%. This indicates that the smaller decreases in test weights of the dried unscoured samples were due mostly to the roughening of the outer bran layers. The

larger decreases which occurred with the greater amounts of wetting and which to a considerable extent persisted after scouring indicated that the swelling which took place as a result of wetting persisted after drying.

The trends in the change of test weight in the samples stored in the laboratory were the same as for those stored in the cold but the decreases were larger. This was due to the development of mold which would cause an additional roughening of the bran coat and also the destruction of some of the wheat substance. In the scoured wheat the decreases in test weight started in several samples at 15% and 16% moisture and became progressively greater as the molds had been more evident.

TABLE VI

VIABILITY OF STORED SAMPLES

Cold storage				Laboratory storage			
Description	3 mos.	6 mos.	9 mos.	Description	3 mos.	6 mos.	9 mos.
Check	Good	Good	Good	Check-air	Good	Good	Weevil eaten
Air-12	"	"	"	Air-12	"	"	Good
Air-14	"	"	"	Air-14	"	"	Very poor
Air-15	"	"	"	Air-15	Poor	Dead	Dead
Air-16	"	"	Fair	Air-16	Dead	Dead	"
Air-18	"	"	"	Air-18	"	"	"
Air-20	"	Fair	"	—	—	—	—
Sealed-12	"	Good	Good	Sealed-12	Good	Good	Good
Sealed-14	"	"	"	Sealed-14	"	Fair	Dead
Sealed-15	"	"	"	Sealed-15	Very poor	Dead	Poor
Sealed-16	"	"	"	Sealed-16	Dead	"	Dead
Sealed-18	"	"	"	Sealed-18	"	"	"
Sealed-20	"	"	"	—	—	—	—

Proximate viability.—The test for viability did not include kernel counts. Weighed amounts, estimated to be about 100 kernels, were placed between blotters, wetted, and placed in a germinator. The examinations by inspection were made after 4 and 7 days. Those in which nearly all kernels had vigorous sprouts were graded good. Those in which about half the kernels had sprouted were graded fair. The difference between fair and good could be only a proximate estimate. Some which had very few short sprouts were graded poor or very poor. Those that showed no signs of germination were designated dead. The results of this examination are given in Table VI. All the sealed samples in cold storage had good germination. Of those under aerobic conditions four were graded fair, namely: the 20% moisture after 6 and 9 months and the 16% and 18% moisture after 9 months. None in cold storage was dead.

For the samples stored in the laboratory, the decreases in viability started with 14% moisture for the 9 months and with 15% for the 3 and 6 months. There were 12 which had good germination, 5 poor to fair, and 16 were dead. Thus both duration of storage and amount of moisture were factors in the decrease in viability. The outstanding fact is the difference between the cold and laboratory storage in preserving the viability.

Flour yield and ash content.—The milling was done on the Buhler mill and at a constant setting of the rolls so as to obtain a uniform extraction as far as possible. The data on flour yields and ash content are given in Table VII. The percentages of flour yields are based on

TABLE VII

FLOUR YIELD AND ASH CONTENT

	Cold Storage				Laboratory Storage			
	3 months		6 months		3 months		6 months	
Description	Yield	Ash	Yield	Ash	Yield	Ash	Yield	Ash
	%	%	%	%	%	%	%	%
Check	76	0.45	71	0.38	76	0.50	73	0.41
Air-12	74	0.45	72	0.39	76	0.52	72	0.39
Air-14	73	0.46	74	0.37	77	0.52	73	0.39
Air-15	75	0.45	73	0.38	76	0.51	71	0.45
Air-16	73	0.45	73	0.38	75	0.49	75	0.50
Air-18	72	0.45	75	0.41	77	0.57	77	0.60
Air-20	73	0.42	72	0.42	—	—	—	—
Sealed-12	73	0.42	76	0.41	75	0.47	75	0.42
Sealed-14	76	0.45	76	0.41	74	0.43	75	0.45
Sealed-15	75	0.42	75	0.42	76	0.48	75	0.43
Sealed-16	73	0.42	74	0.42	75	0.51	74	0.51
Sealed-18	75	0.48	75	0.45	77	0.59	75	0.42
Sealed-20	76	0.50	74	0.45	—	—	—	—

the amount of wheat milled and do not show any definite trends which can be related to the storage conditions. The moisture percentages of the flours were very uniform, most samples ranging from 13.4 to 13.7, with an extreme spread of 13.0 to 13.8. The average of all was 13.5%. The ash figures were corrected to the 15% moisture basis. In most samples, the ash is lower in the flour from the 6 months than from the 3 months storage, and there is also a trend toward an increase in ash for the higher moisture samples. This trend was greater for those stored in the laboratory due to the mold than for the samples stored in the cold which were not moldy.

Baking tests.[3]—The following formula was used in making the baking tests:

100 g. flour	1.5 g. salt
2 g. yeast	3 g. shortening
6 g. sugar	1 mg. potassium bromate

[3] Credit is due Mr. Meade Harris, American Dry Milk Institute Fellow, 1939–40, for making the baking tests.

The details of performing the baking tests were the same as for the previous year. The most significant figures, loaf volumes and the average of the baking scores, are given in Table VIII. Figures are also given for the loaf numbers represented in Figures 3 and 4. A

TABLE VIII

BAKING RESULTS

	3 months storage						6 months storage					
	Cold			Laboratory			Cold			Laboratory		
Description	Vol. cc.	Score %	No. on photo	Vol. cc.	Score %	No. on photo	Vol. cc.	Score %	No. on photo	Vol. cc.	Score %	No. on photo	Odor of dough
Check	733	87	7	725	86	1	725	87	7	731	87	1	—
Air-12	790	93	13	718	85	2	820	95	13	730	87	2	—
Air-14	785	93	14	778	91	3	830	96	14	770	91	3	+
Air-15	843	99	15	770	87	4	845	98	15	715	82	4	++
Air-16	793	96	16	743	83	5	855	98	16	642	66	5	+++
Air-18	788	91	17	570	56	6	860	99	17	530	49	6	++
Air-20	795	92	18	—	—	—	842	96	18	—	—	—	++
Sealed-12	753	87	19	793	94	8	792	93	19	778	93	8	—
Sealed-14	778	90	20	765	83	9	848	98	20	822	96	9	—
Sealed-15	800	95	21	805	84	10	865	101	21	840	97	10	+
Sealed-16	813	91	22	720	67	11	885	100	22	595	57	11	++
Sealed-18	775	88	23	540	40	12	852	97	23	438	32	12	++
Sealed-20	725	76	24	—	—	—	815	92	24	—	—	—	++

number of the stored samples gave better results than the check samples, especially those stored in the cold for six months. The following six samples showed distinctly lower values than the checks:

3 MONTHS	6 MONTHS
L-18-air	L-16-air
L-18-sealed	L-18-air
	L-16-sealed
	L-18-sealed

The wheats of all of these were dead as shown in Table VI. The following dead samples gave baking results almost equal to the checks:

3 MONTHS	6 MONTHS
L-16-air	L-15-air
L-18-sealed	L-15-sealed

These were next to the samples which had some or good viability. Thus if a sample is dead it may be only slightly or may be severely damaged. Good viability is a sign of no serious damage.

The dough from four of the laboratory-stored samples which had a lower baking value than the checks had a distinct foreign odor. The intensity of the odor is designated by the number of + signs. This odor was also noticed in three samples which had baking figures equal to the checks. Thus a dough which has a slight odor due to damage in the wheat may still give good baking performance. The odor in the dough compares with the viability test as among the most sensitive tests for damage.

A few specific gravity determinations made on samples differing widely in storage conditions did not show any correlation with the various treatments these samples had received. One reason for this may be that the wheat used in this experiment had undergone considerable weathering during harvest.

Curves on the recording dough mixer.—Curves on the recording dough mixer were made on a selected number of flours from the six-months storage lot. Several of these flours were extracted with petroleum ether for six days. After removal from the extractor, they were exposed to allow the ether to evaporate. Representative curves from both extracted, unextracted, cold, and laboratory storage are given in Figure 5.

Curve characteristics are due to two sets of factors: (1) those which are inherent in the gluten structure and (2) those which surround the gluten material. The former determines types of curves such as obtained from Tenmarq and Chiefkan. The second set of factors includes added salts, acids, or certain fatty materials. Fatty substances are most easily altered under unfavorable storage conditions. The purpose of extracting flours with ether was to ascertain whether the removal of the ether-extractable material would have any effects on the curve characteristics.

The two upper rows are from the samples stored in the cold and all the rest are from the laboratory-stored samples. No great amount of change was produced in the curve characteristics of those stored in the cold even with 18% and 20% moisture, nor were those from the ether-extracted notably different from the unextracted. Thus these curves corroborate the other tests, showing that no damage, or very little, had occurred in the samples stored in the cold.

The curves from the laboratory samples tell a different story. Curves 11 and 12 from the samples with 15% moisture show distinctly the beginning of those changes which were much more manifest when the moisture content was 16%; note curves 13, 14, 15, and 16. The extraction with ether had no effect that might not be due to variation in absorption. The amount of damage was still greater when the moisture was 18% as shown in curves 17, 18, 19, and 20. When the damage is very great as in this case the dough behaves more like a plastic mass, as shown in curves 17 and 18, which show no rise in the normal length of the curves. If the time of mixing is continued long enough, there will be a slow rise as shown in curves 19 and 20.

The curves presented show that the type of damage which had occurred in these samples is revealed by curve characteristics as well as by the baking tests.

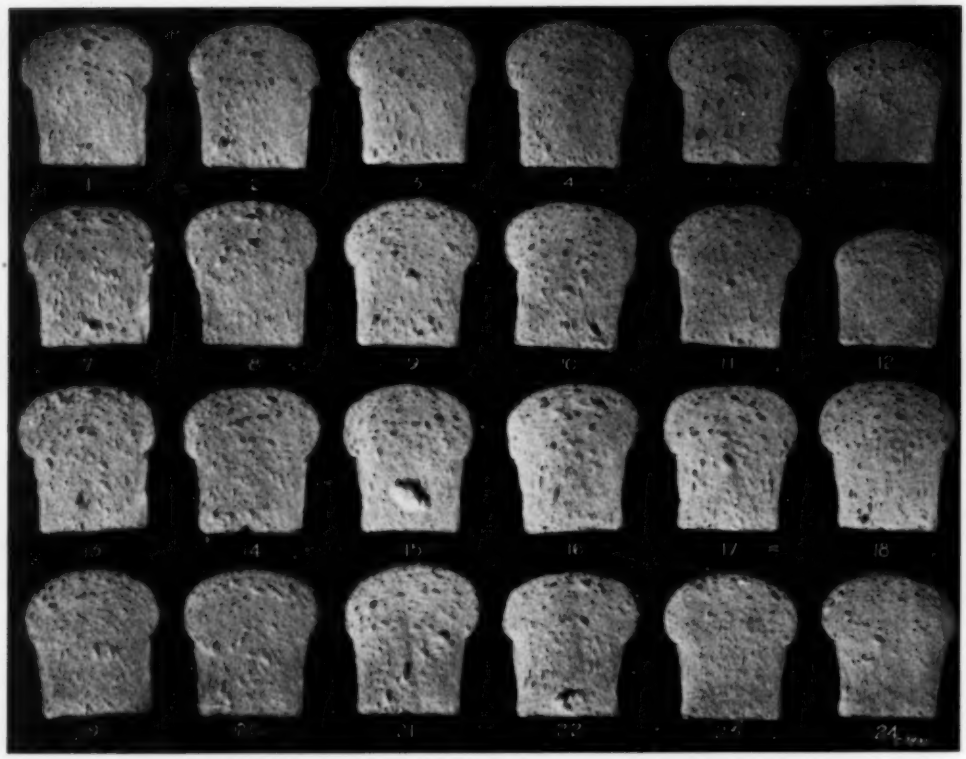

Fig. 3. Photographs of loaves from the three-months storage samples.

Loaf No. on photograph	Sample No.	Baking No.	Loaf No. on photograph	Sample No.	Baking No.
1	L-3	19	13	C-12-A	16-1
2	L-12-A	3	14	C-14-A	17-1
3	L-14-A	4	15	C-15-A	18-1
4	L-15-A	5	16	C-16-A	20
5	L-16-A	6	17	C-18-A	1
6	L-18-A	7	18	C-20-A	2
7	C-3	15-1	19	C-12-S	8
8	L-12-S	14	20	C-14-S	9
9	L-14-S	15	21	C-15-S	10
10	L-15-S	16	22	C-16-S	11
11	L-16-S	17	23	C-18-S	12
12	L-18-S	18	24	C-20-S	13

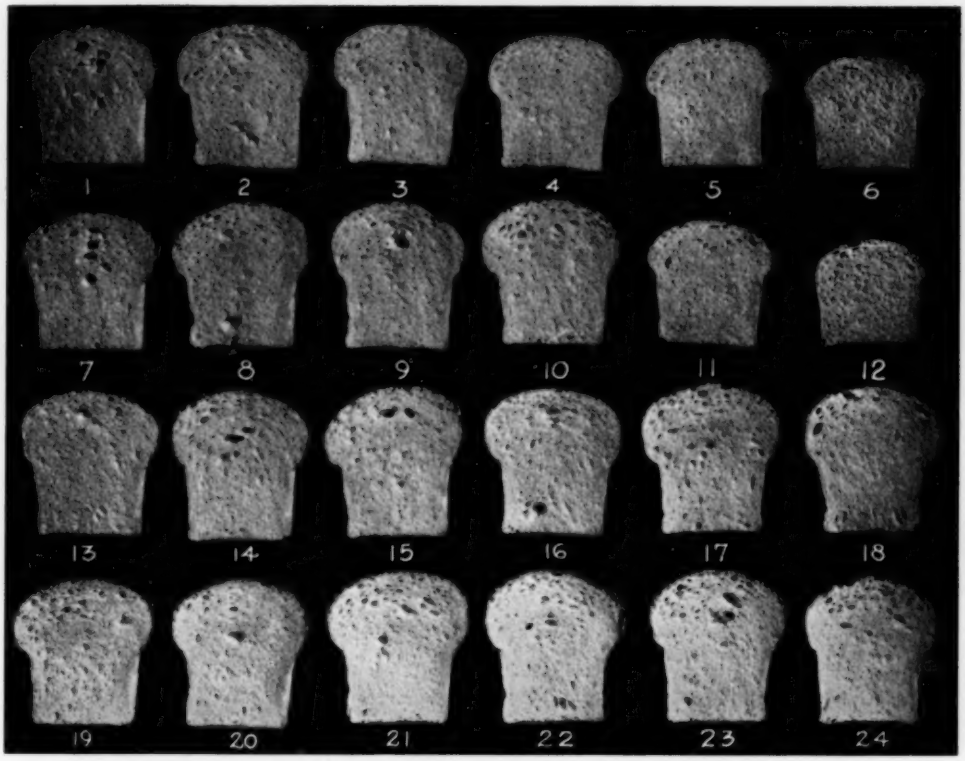

Fig. 4. Photographs of loaves from the six-months storage samples.

Loaf No. on photograph	Sample No.	Loaf No. on photograph	Sample No.
1	L-6 check	13	C-12-A
2	L-12-A	14	C-14-A
3	L-14-A	15	C-15-A
4	L-15-A	16	C-16-A
5	L-16-A	17	C-18-A
6	L-18-A	18	C-20-A
7	C-6 check	19	C-12-S
8	L-12-S	20	C-14-S
9	L-14-S	21	C-15-S
10	L-15-S	22	C-16-S
11	L-16-S	23	C-18-S
12	L-18-S	24	C-20-S

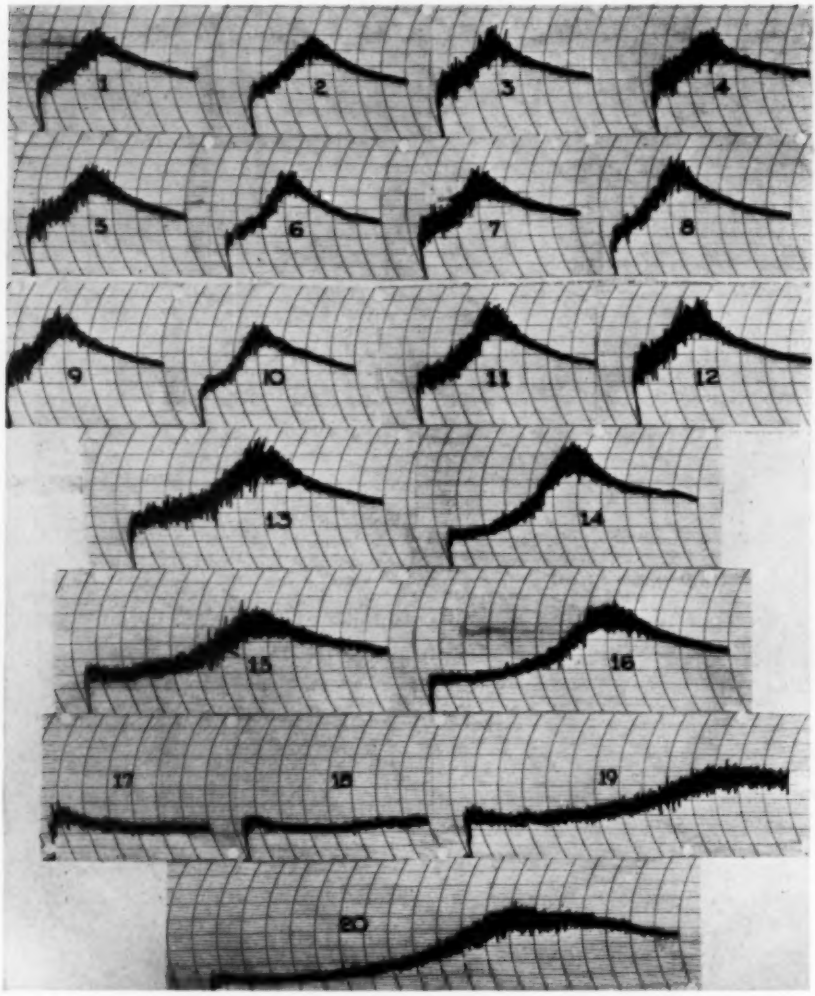

Fig. 5. Dough-mixer curves on the cold and the laboratory-stored samples.

Cold storage

(1) C—check 63%
(2) C—check extr. 75%
(3) C—18 air 64%
(4) C—18 sealed 65%
(5) C—20 air 61%
(6) C—20 air extr. 69%
(7) C—20 sealed 63%
(8) C—2 sealed extr. 68%

Laboratory storage

(9) L—check 63%
(10) L—check extr. 71%
(11) L—15 air 64%
(12) L—15 sealed 63%
(13) L—16 air 62%
(14) L—16 air extr. 72%
(15) L—16 sealed 62%
(16) L—16 sealed extr. 68%
(17) L—18 air 59%
(18) L—18 air extr. 67%
(19) L—18 air sealed 60%
(20) L—18 sealed extr. 68%

Summary

Two years' work on storing wheat samples at various moisture contents in the laboratory and at 41°F. have been presented. Variations in air supply and duration of time were introduced the second year. The main tests used to measure the effects of these conditions during storage were: viability, test weight, soundness of grain, milling and baking tests, and curves made on the recording dough mixer.

There was no decrease in viability in the samples stored in the cold, while all those stored at higher moistures in the laboratory were dead. Wheat of good viability shows no damage to its milling and baking qualities. Unsoundness, as indicated by mustiness, developed at lower moistures in the laboratory than in the cold storage. In the latter, sourness developed in the samples with the higher moistures. This kind of damage was not reflected in the results of the baking tests. In fact these tests were shown to be much less capable of detecting damage than the viability and the odor tests. The altered curve characteristics obtained on the damaged samples were not due to changes in the ether-extractable substances but were due to alteration in gluten characteristics.

Wheat may be stored at 41°F. at high moisture for many months without suffering any damage to its milling and baking qualities. When wheat has good viability it has suffered no damage to the gluten structure even when a slight odor indicating unsoundness can be detected.

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AMERICAN WHEAT TYPES AND VARIETIES AS DISTINGUISHED BY FARINOGRAMS AND EXTENSOGRAMS

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I. Testing Soft Wheat Flours

The application of practical baking tests to the testing of soft wheat flours has not proved to be entirely satisfactory. These flours are used for a diversity of purposes in the baking of biscuits, cakes, pastries, and crackers. Accordingly the development of a single baking test that will disclose the adaptability of any flour to several of these purposes is not feasible. Moreover, it is difficult to simulate in the laboratory the conditions to which the flour will be subjected in certain commercial baking operations.

Chemical analyses and such physical tests as the viscosity of acidulated flour suspensions have proved of service in the soft wheat flour industries. None of these have proved wholly adequate, however. The farinograph served to advance such testing procedures and has afforded one means for classifying wheat types and varieties to a degree that was not possible prior to its application to such studies.

Thus, as indicated by the six farinograms in Figure 1, there are sharp differences discernible in the behavior of such flours when thus tested. Various samples of soft red winter wheat produced in Illinois differed widely, as disclosed by farinograms *A* and *B* at the top of the figure. Sample *A* is typical of a weak flour of this class, while sample *B* is distinctly on the strong side. Both farinograms are different from that which resulted from testing the sample of Federation. The latter is typical of the flours milled from this variety, and less variability was encountered among the several samples of this, and of the White Club and Soft White types. This facilitates the identification of individual samples in such instances. Thus the White Club farinogram discloses very rapid dough development to the maximum consistency, together with a wide curve which does not diminish substantially in width, but decreases steadily in consistency with extended mixing. This is the farinogram of a flour adapted particularly to pastry and cookie baking.

Federation wheat flour yielded a farinogram which also disclosed a rapid dough development, followed by an interval during which the consistency changed very little, although the curve width decreased appreciably. Thereafter a substantial decrease in consistency was regis-

tered. In general the curve width was narrower than the White Club, and the general outline of the curve was markedly different from the latter. Absorption to yield a unit maximum consistency was 2%–3% greater in the Federation than in the White Club flour sample.

Soft white wheat (Michigan) flour was intermediate between the Federation and White Club in many respects, although the curve width
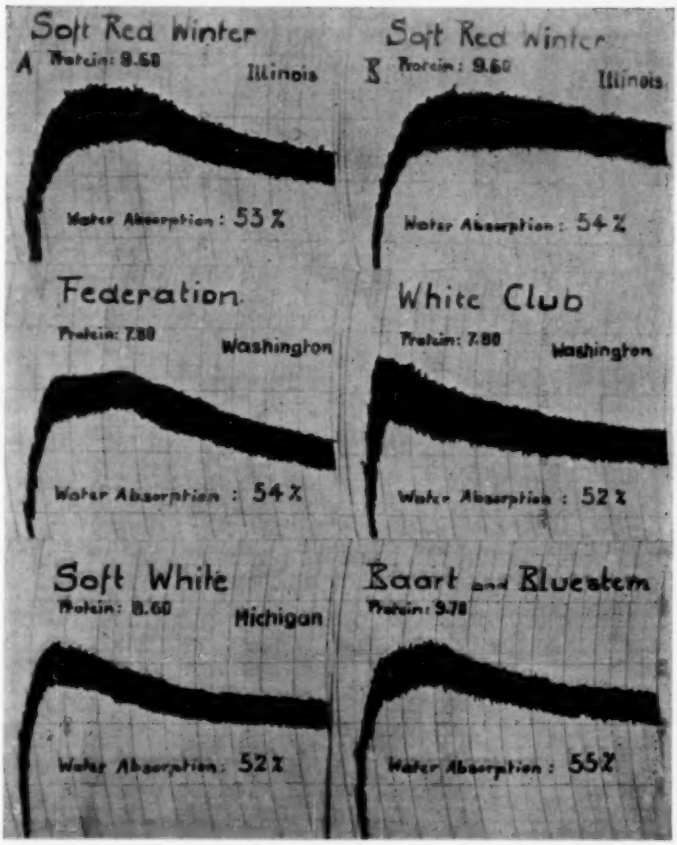
Fig. 1. Farinograms of prominent American soft wheat varieties and classes.

was narrower. Also the dough became quite sticky, which contributed to the irregularity of the farinogram. Absorption was in the same range as the White Club. Such flour is adapted to the baking of angel food cake.

Baart and Pacific Bluestem wheat flour yielded a farinogram disclosing a slower rate of dough development than the Federation, White Club, and Michigan Soft White wheat flours. In this respect it was similar

to the Soft Red winter wheat flours, but differed in having a narrower curve width. Water absorption was higher than with the other soft wheat flours. At the same level of protein content the Baart-Bluestem flour farinograms might be expected to resemble the Federation flour farinograms, but most of the Baart and Bluestem wheat of commerce tends toward an appreciably higher protein content, which distinguishes it from the Federation wheat.

Experience has indicated that certain wheat types and varieties yield such distinctive farinograms (when corrected to a known or constant protein level) that they can be distinguished by farinograph tests. The latter may even serve to indicate the kinds of wheat in a mixture and thus be of practical service in duplicating blends in competitive flour production. In interpreting farinograms consideration must be given to protein content, extraction in milling (which is reflected in part in

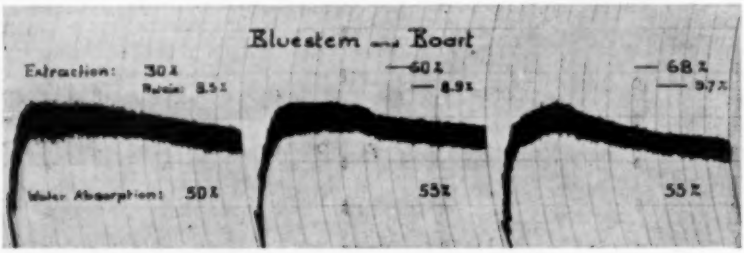

Fig. 2. Influence of percentage of flour extraction on farinogram.

the ash content), and granulation of the flours under test. The latter is of least consequence in terms of its direct effect upon the shape of the farinogram, but may be of major significance in practical cake baking.

Extraction in milling is of large consequence, however, as demonstrated by the three farinograms in Figure 2. These represent flours from the same mill mixture of Baart and Bluestem but milled to 30%, 60%, and 68% extraction [1] respectively. The farinograms differ as greatly as do farinograms of flours from different wheat varieties. It should be stressed here that the six flours represented by the farinograms in Figure 1 were all of about the same percentage extraction, namely 68%, and accordingly are directly comparable so far as flour characteristics are concerned.

Effect of Certain Flour Treatments

Certain flour treatments, notably with oxidizing agents, are not disclosed by the farinograph, however, and in order to adequately study

[1] Extraction is recorded here in the European manner, namely, in terms of the percentage of the original wheat, rather than in terms of the percentage of total flour.

their effect upon dough properties, recourse should be had to the extensograph. A significant indication of the usefulness of the extensograph in testing soft wheat or pastry flour doughs is indicated by the graphic records of Figures 3 and 4. In Figure 3 appear the extensograms [2] of

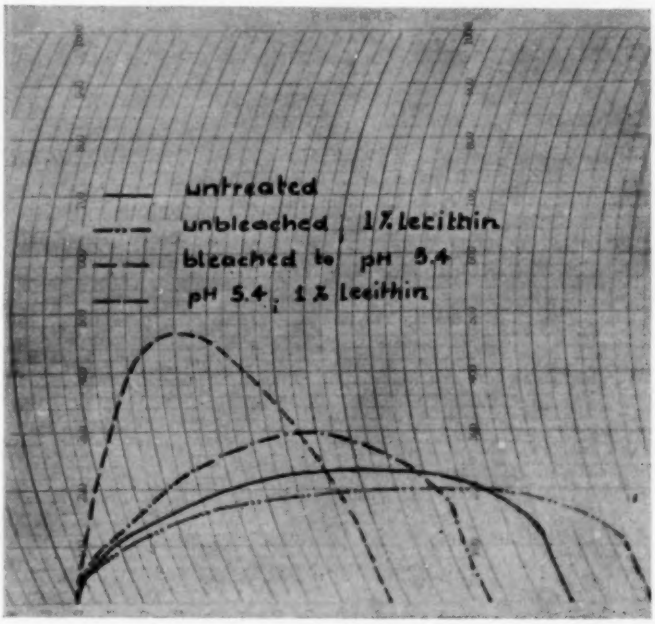

Fig. 3. Extensogram data showing the results of the treatments indicated.

Fig. 4. Photographs of cookie baking tests involving the treatments indicated.

doughs made from a single flour treated in different ways, and compared with the untreated flour. The treatments included (1) addition of 1% of lecithin, (2) bleaching with Cl_2 to pH 5.4, and (3) a combination of lecithin and bleaching.

[2] For a discussion of extensograms see the first paper in this series, "Prediction of baking value from measurements of plasticity and extensibility of dough—I," Cereal Chemistry 17: 78–100, January 1940.

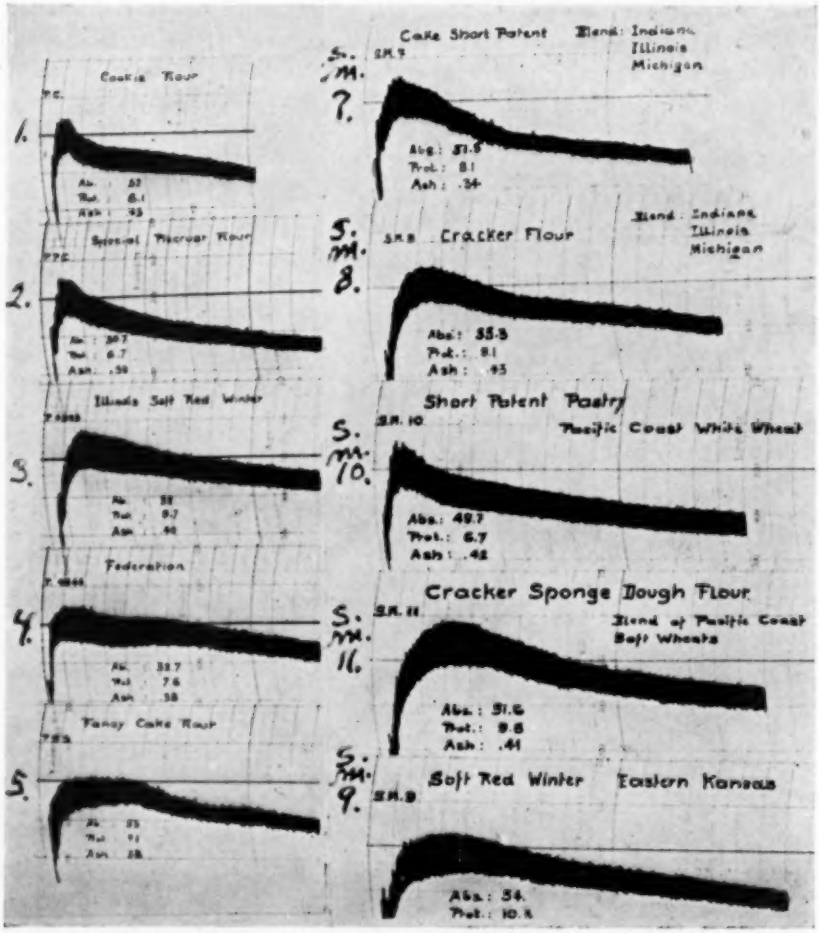

Fig. 5. Farinograms of several types of soft wheat flour.

Fig. 6. Farinograms of cake, cracker and pastry flours.

Superimposing lecithin upon the untreated flour resulted in increasing the extensibility of the resulting dough, as evidenced by the increase of the extensogram along its horizontal or E axis. Bleaching to pH 5.4 with Cl_2 had the reverse effect, decreasing the extensibility E, sharply increasing the force F to extend the dough as recorded on the vertical axis, and thus substantially altering the F/E ratio. When lecithin was then superimposed upon the chlorine-bleached flour dough, there was a tendency toward regaining the characteristics of the untreated flour dough, although the E value of the latter was still greater and its F value significantly less than that of the dough with the combined lecithin and Cl_2 treatment.

Figure 4 shows photographs of cross sections of cookies baked from the four doughs which are represented in Figure 3. The round disks of dough from which the cookies were baked were uniform in the raw state. The effect of lecithin upon the "spread" of the cookie doughs is evident from the increased diameter. Chlorine bleaching (3rd row) evidently "tightened up" the dough and reduced the "spread" or flow in baking considerably. Again, the combination of Cl_2 and lecithin treatments (4th row) tended to restore the properties of the untreated flour dough. The correlation between the extensograms and the cookie baking tests is striking.

Classifying Soft Wheat Flours for Special Purposes

Differences between individual flours milled from soft wheats are demonstrated by the farinograms and extensograms represented in Figures 5, 6, 7, 8, and 9. Thus the farinogram numbered 5 (Fig. 5) and 7 (Fig. 6), representing flours used for cake baking, were milled from

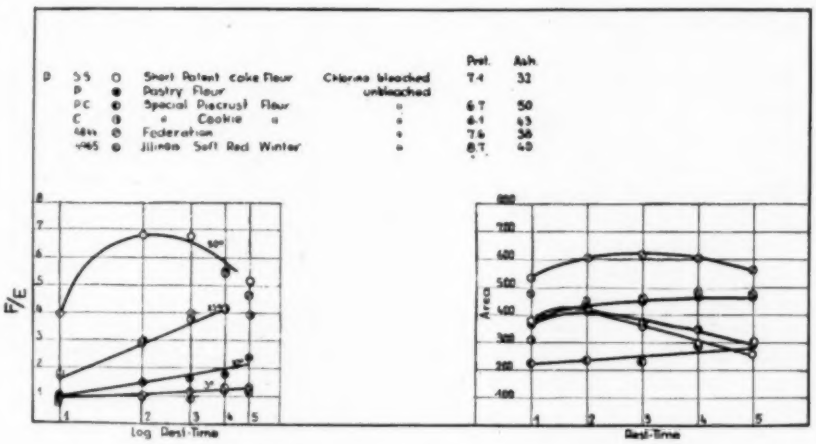

Fig. 7. Extensogram data of the flours for which farinograms are shown in Figure 5.

different types of wheat than the flours yielding farinograms numbered 1 (Fig. 5) and 10 (Fig. 6), which last two are typical cookie and pastry flours. These latter resemble the White Club flours, while 5 and 7 appear to have been blends of soft white and soft red winter wheat flours.

Cracker dough flour numbered 8 (Fig. 6) yielded a farinogram of the same general characteristics as the soft red winter wheat flours shown in Figure 1. The cracker sponge flour farinogram (No. 11) is somewhat wider than the cracker dough flour (No. 8). Extensograms of these two flours are quite different (Fig. 8), occupying the upper posi-

tion (No. 8) and the lowest position (No. 11) in the F/E ratios shown at the lower left of the figure.

This discloses that the cracker dough flour resisted extension, *i.e.* had a relatively high F value, but exhibited little extension, *i.e.* the E value was low, and hence the F/E ratio was high after several hours of rest time had been allowed to the dough under test. Since the time of fermentation in the sponge stage is much longer than in the dough stage in cracker manufacture, it might well follow that doughs made from both of these flours would yield similar extensograms if fermented for the widely different periods of time accorded them under commercial conditions.

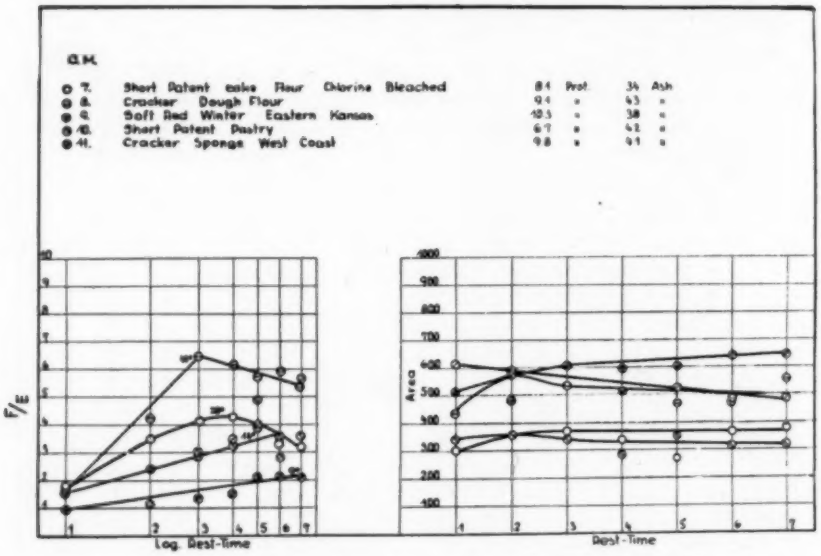
G.M.
7. Short Patent cake Flour Chlorine Bleached 8.4 Prot. 34 Ash
8. Cracker Dough Flour 9.4 " 43 "
9. Soft Red Winter Eastern Kansas 10.3 " 38 "
10. Short Patent Pastry 6.7 " 42 "
11. Cracker Sponge West Coast 9.8 " 41 "
F/E
Area
Log. Rest-Time
Rest-Time

Fig. 8. Extensogram data of the flours for which farinograms are shown in Figure 6.

The two pastry and cookie flours, Nos. 1 (Fig. 5) and 10 (Fig. 6) yielded farinograms of the same general character, and it has already been suggested that these indicate White Club wheat as the principal constituent of the mill mixture. Their extensograms (Figs. 7 and 8) also have some features in common, both in F/E ratios and area, and exhibited only a small or moderate change in the F/E ratio with an increasing rest time. The special pie crust flour No. 2 (Fig. 5), designated " P.C." in Figure 7, also yielded a farinogram indicating that it might have been milled from White Club wheat. Its low protein content is probably reflected in the small area under the extensogram, recorded graphically at the right in Figure 7. The lack of change in the F/E

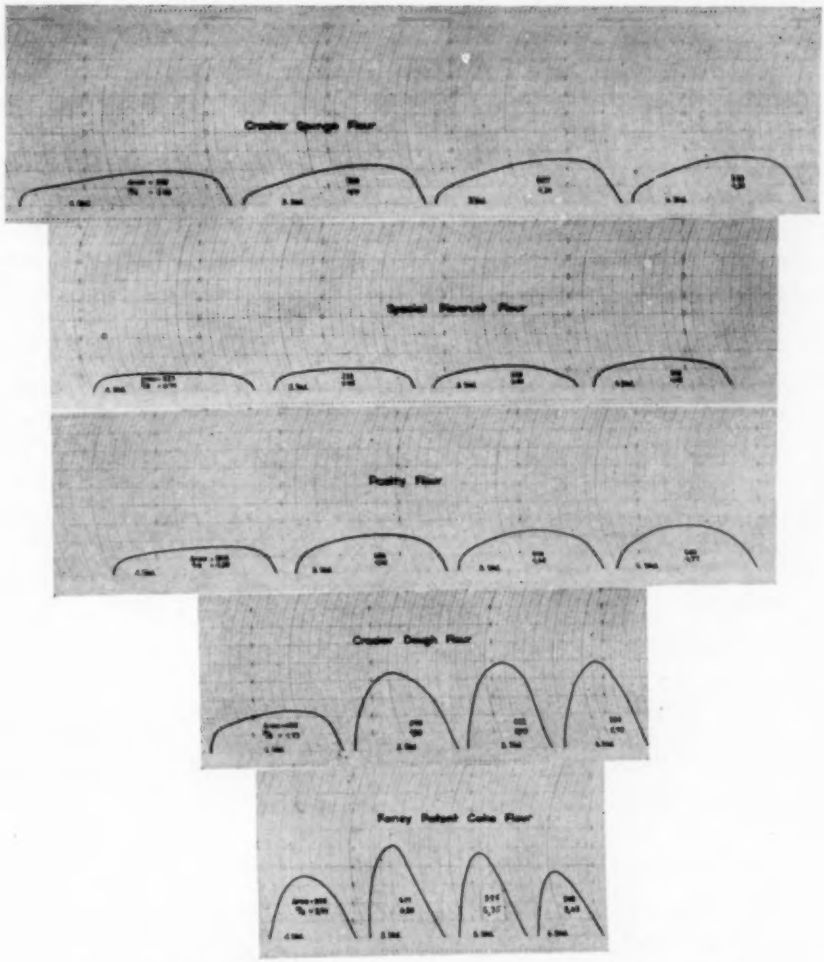

Fig. 9. Actual extensograms for which the data are recorded in Figures 7 and 8. ("Std." is the abbreviation of "Stunde," the German word for *hour*.)

ratio with increasing rest time may be the consequence, in part, of its relatively high ash content.

The actual extensograms of five of the flours from which certain of the constants recorded in Figures 7 and 8 were computed, are shown in Figure 9. The F/E ratio of the "special pie crust flour" is obviously very low, and changes little between the first hour, labeled "1 Std.", the abbreviation of *Stunde* (German for hour), and the fourth hour of rest after mixing. The "pastry flour" ranked second in these particulars, followed by the cracker sponge and cracker dough flours in the order named. The "fancy patent cake flour" was quite distinc-

tive, with a relatively high F/E ratio, passing through a maximum after standing two hours and then receding somewhat. The area under the extensograms is not large, however, and it is probable that this combination of properties may be a reflection of the short extraction of this flour and the bleaching treatment accorded it.

In Table I we present a consolidated summary of the characteristics of several types of flour, based upon certain broad, general opinions of the American baking industry. It is recognized that limits cannot be expressed too definitely, however, since bakers are not uniformly agreed as to what represents an ideal flour for every specific purpose.

TABLE I

GENERAL CHARACTERISTICS OF FLOURS DESIGNED FOR CERTAIN SPECIAL PURPOSES

Characteristic	Short patent cake flour [1]	Cookie flour	Cracker flours	
			Dough	Sponge
Extensograph area	300–450	350–500	500–600	600–700
Specific form [2]	>3½	2½–3½	4–6	1–2
Crude protein, %	—	6.5–7.5	—	—
Ash, %	0.32–0.34	0.38–0.43	0.40–0.44	0.40–0.44
Granulation	Very fine	Coarse	Medium	—
pH	5.3–4.8(Cl_2)	—	—	—
Water absorption [3] (15% basis)	—	49–52	54–57	—

[1] Especially for angel food and layer cake.
[2] Specific form is the F/E ratio after 2½ hour rest period.
[3] Consistency level 500 Brabender farinograph units. Farinogram of short patent cake flour should range between S.M. 7 in Figure 6, and No. 5 in Figure 5. Farinogram of a cookie flour should resemble No. 1 in Figure 5, reaching maximum consistency early, and then decreasing rapidly in consistency thereafter, but without a major decrease in the curve width. Farinogram of a cracker dough flour should conform to curve marked S.M. 8 in Figure 6. Farinogram of a cracker sponge flour should indicate somewhat greater strength than that of the cracker dough flour.

II. Testing Hard Wheat Flours

The laboratory baking test has been more useful in testing hard wheat flours than soft wheat flours, but still it does not give all the desired information. The blending value of a flour is inadequately indicated by this test. The baker's judgment of the dough behavior during fermentation cannot be recorded with satisfaction. Of course it is possible to record the volume and appearance of the finished loaf, but deductions from the latter concerning dough properties or blending possibilities of a flour are often vague and unreliable. Thus it is shown in Table II that volume, score, and fermentation time can be nearly the same with flours of equal protein content but of decidedly different dough properties. The different wheat varieties compared are known to have quite different dough properties but still their loaf volumes and bread scores compare within the experimental error. Whereas the baking technologist who carried out these tests could distinguish the widely different

flours from their appearance in the dough stage, such discrimination was not possible with the loaves baked from these flours. Since the quality of a flour is not only determined by the finished loaf but equally well by the behavior of the dough during the various dough manipulations it follows that the customary baking test is at times inadequate.

This explains why the present trend of cereal research is towards physical methods of dough testing. In two earlier papers (footnotes 2 and 3) some basic principles of dough reactions such as are revealed by

TABLE II

DATA ON FLOURS HAVING DIFFERING DOUGH PROPERTIES

Grade	Class of wheat	State where grown	Crude protein, % in 60% extraction flour	Volume (*cc.*) Fermentation time in hours			Score Fermentation time in hours		
				3	4	5	3	4	5
1 DK	Hard Red Spring	N. D.	13.1	2530	2475	2475	92	90	89
1 DHW	Dark Hard Winter	Kan.	12.3	2515	2490	2475	92	90	89
1 HWh	Hard White	N. D.	12.8	2460	2475	2420	91	90	87
1 DHW	Dark Hard Winter	Okla.	12.4	2430	2430	2420	90	89	88
2 D° Sp.	Hard Red Spring	Ill.	13.1	2585	2515	2460	93	91	88
1 HS	Hard Spring	—	13.7	2490	2475	2475	91	91	90
2 HWh	Hard White	N. D.	12.8	2530	2475	2475	90	91	90
Average			12.9	2505	2476	2457	91	90.3	89
2 HWh	Hard White	—	11.8	2430	2460	2375	89½	89½	87½
2 DK° Sp.	Dark Spring	Ill.	11.5	2475	2475	2445	90	88½	87
3 HW	Hard Winter	Neb.	11.7	2405	2375	2360	90	88	88½
2 DHW	Dark Hard Winter	Mont.	11.7	2445	2390	2360	91	88½	87
HRW	Hard Red Winter	Ill.	11.0	2460	2475	2390	93	90½	87½
HW	Hard Winter	Kan.	11.2	2430	2415	2390	90	89	87½
1 DK	Dark Spring	Ill.	11.7	2460	2430	2430	90½	88	87
2 HW	Hard Winter	Minn.	11.7	2445	2460	2330	91½	90	88½
2 X	Not classified	Kan.	11.3	2460	2445	2415	90	90½	87
1 D° Sp.	Dark Spring	Ill.	11.4	2460	2445	2360	91	90½	87
1 HW	Hard Winter	Neb.	11.2	2475	2445	2430	90½	90	88
Average			11.5	2449	2437	2380	90.7	89.2	87.5

the farinograph and extensograph were discussed. The flours used for the experiments were mostly of commercial origin. The following section discusses data derived from testing semicommercially milled flour from special wheat samples obtained from various flour mills, and from pure wheat varieties obtained from the Northwest Crop Improvement Association. In case of the wheat variety samples the general baking behavior had been indicated in broad terms by the mills, while the general rating as regards baking quality of the pure wheat samples could be taken from a report of the Northwest Crop Improvement Association, which consolidates and summarizes the results of individual collaborative baking tests.

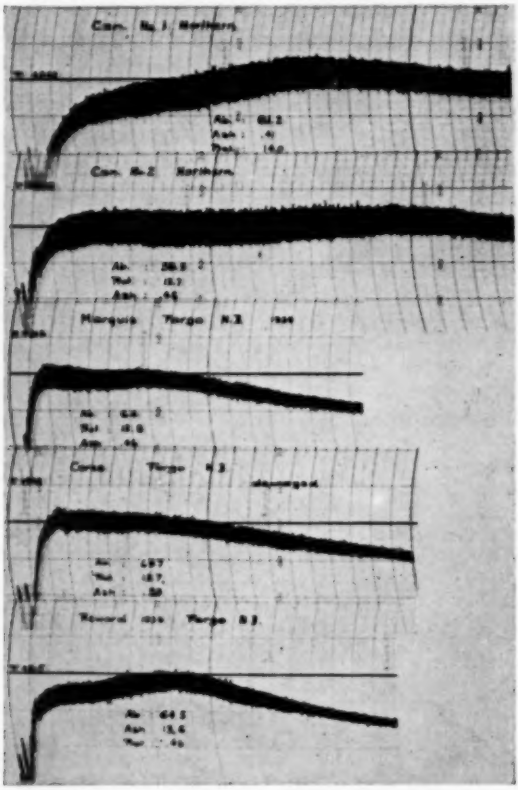

Fig. 10. Farinograms of the first series of hard spring wheat flour samples.

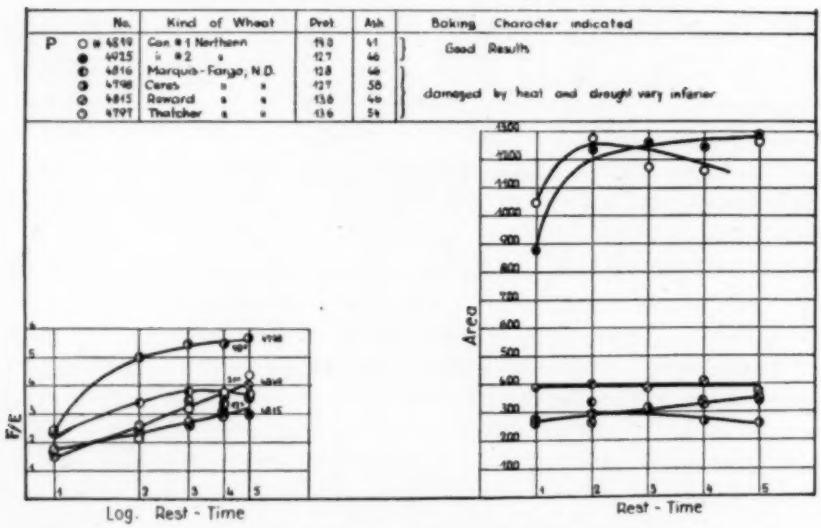

Fig. 11. Extensogram data of the flours for which the farinograms are shown in Figure 10.

In the rating of flours according to extensogram data primary consideration was given to curve surface; however, in instances of similar surfaces preference was given to flours which yielded doughs of larger extensibilities.

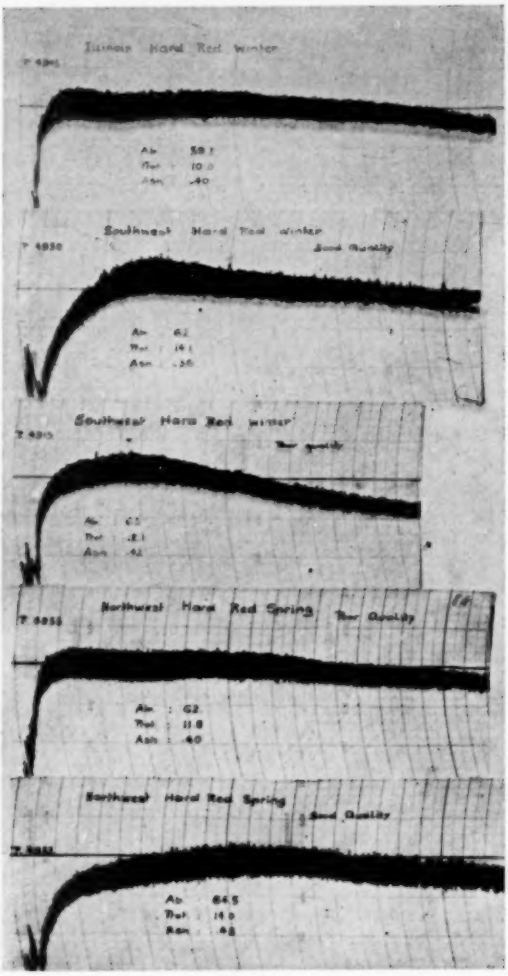

Fig. 12. Farinograms of the second series of hard wheat flours.

Certain relationships between farinograms and extensograms of hard wheat flours become apparent on comparing the data recorded in Figures 10 and 11. In Figure 10 the third, fourth, and fifth farinograms suggest flours milled from wheats that have been damaged by weather conditions such as drought. These faults are evidently reflected in the area

under the extensograms recorded at the lower right in Figure 11. On the other hand, the "strong" farinograms of the two Canadian flours are supported by the large area under their extensograms. Moreover the extensograms suggest a substantial positive response to bromate treatment, since their oxynumbers $\left(\frac{\text{Area}}{F/E \times 10}\right)$ of 51 and 42 respectively are in the positive range indicated by Munz and Brabender.[3] Canadian flours of the type represented by these flours are known to exhibit positive responses to bromate treatment.

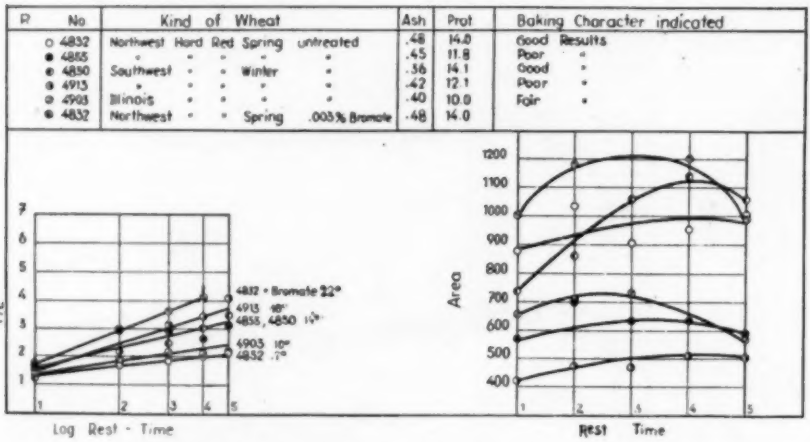
P No
Kind of Wheat
Ash
Prot
Baking Character indicated
4832 Northwest Hard Red Spring untreated .48 14.0 Good Results
4855 " " " " .45 11.8 Poor "
4850 Southwest " " Winter " .36 14.1 Good "
4913 " " " " .42 12.1 Poor "
4903 Illinois " " " .40 10.0 Fair "
4832 Northwest " " Spring .005% Bromate .48 14.0
F/E
Area
4832 + Bromate 22°
4913 18°
4855, 4850 14°
4903 10°
4832 7°
Log Rest - Time
Rest Time

Fig. 13. Extensogram data of the flours for which the farinograms are shown in Figure 12, together with ash and protein content, and the baking characteristics disclosed by the collaborative tests of the Northwest Crop Improvement Association.

A second series of five hard wheat flours were subjected to study, and the resulting farinograms are shown in Figure 12. The first of these hard red winter flours (upper farinogram) is representative of a type possessed of only fair baking quality. The second in order is of good quality, while the third is poor. In fourth position is a poor quality of hard spring wheat flour. This, and the first or upper farinograph, are typical of flours possessed of "short" gluten. The curves show a rapid dough development which reaches maximum consistency and curve width in about half the time that is required in mixing such strong flours as are represented by the second and the fifth farinograms.

Extensograms of the same five flours were correlated with the farinograms as shown by their analyses recorded graphically in Figure 13. The two superior flours mentioned above (Nos. 4832, spring wheat, and 4850, winter wheat) yielded extensograms with an area of 1000 to 1200.

[3] Emil Munz and C. W. Brabender: Extensograms as a basis of predicting baking quality and reaction to oxidizing agents, Cereal Chem. 17: 313–332, May 1940.

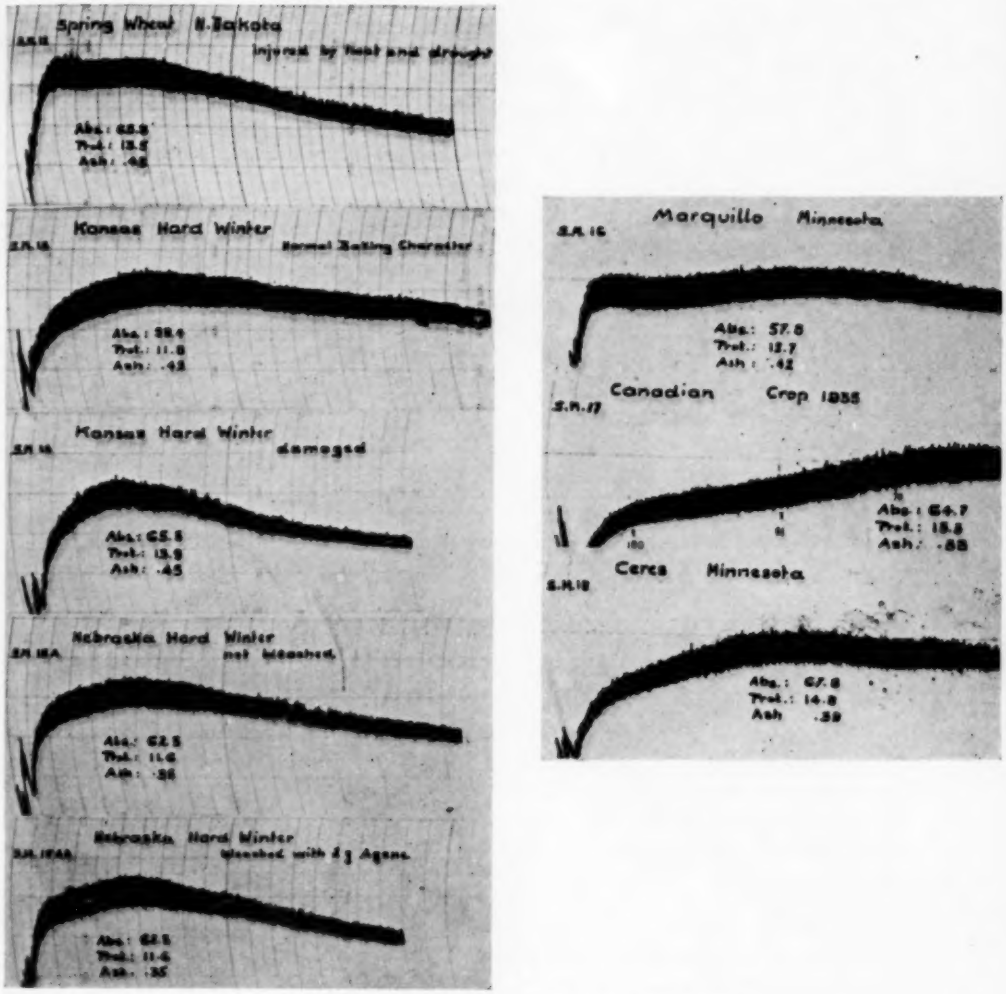

Fig. 14. Farinograms of the third series of hard wheat flours.

The oxynumber of the winter wheat flour was 45, that of the spring wheat flour 28, which is in keeping with their known reaction to oxidizing agents.

A third series of eight flours was then tested, and the farinograms are shown in Figures 14*a* and 14*b*. From these curves the spring wheat flours would be rated in the following order of baking quality, Nos. 17, 18, 16, and 12. The last named behaved as though it was milled from wheat that had been injured by heat and drought before harvest. The area under its extensograms (Fig. 15) was also low, and in the range of

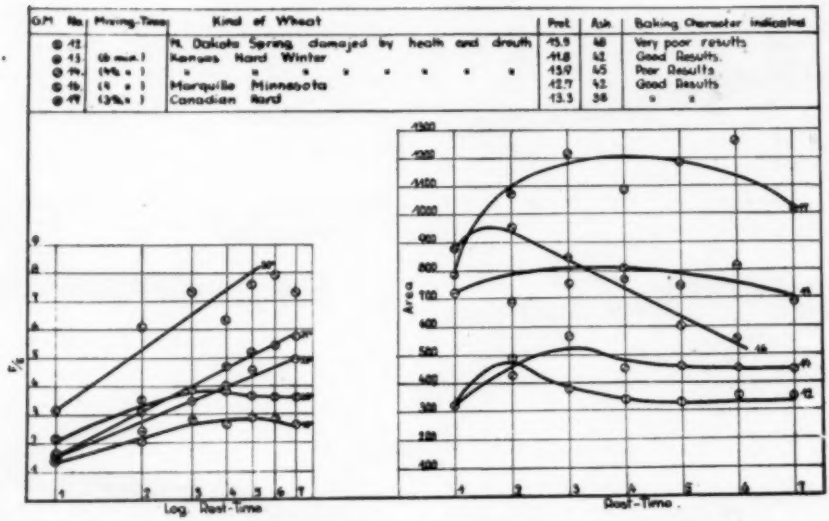
G.M. No. | Mixing-Time | Kind of Wheat | Prot. | Ash | Baking Character indicated
12 | | N. Dakota Spring, damaged by heath and drouth | 15.9 | 48 | Very poor results
13 | (6 min.) | Kansas Hard Winter | 11.8 | 42 | Good Results.
14 | (4½ ") | " " " " " " " | 13.9 | 45 | Poor Results
16 | (4 ") | Marquillo Minnesota | 12.7 | 42 | Good Results
17 | (3½ ") | Canadian Hard | 13.3 | 38 | " "
Log. Rest-Time
Area
Real-Time

Fig. 15. Extensogram data and baking characteristics of the flours for which the farinograms are shown in Figure 14.

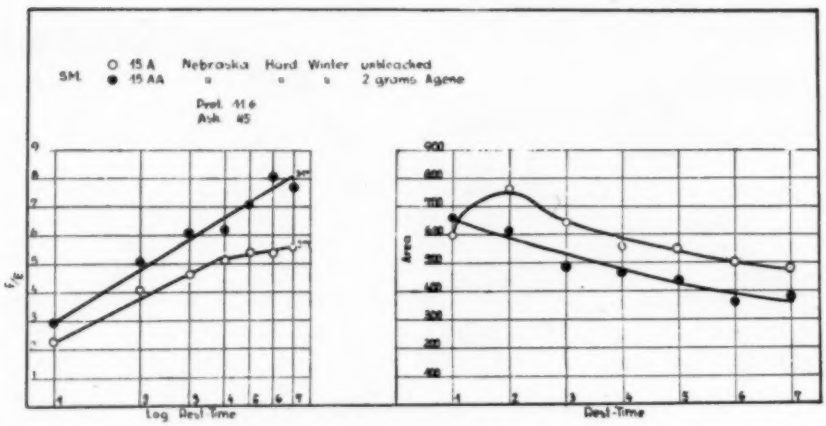

Fig. 16. Extensogram data of a Nebraska hard winter wheat flour, untreated, and treated with Agene.

470 at the maximum. The Marquillo (G.M. 16) farinogram suggested a short gluten, and this was supported by the graph of its extensogram areas with progressing rest time shown at the right in Figure 15. After the second hour of rest, the area decreased sharply with the lapse of time. It likewise had a low oxynumber, 13, which further demonstrated its "short" character.

The superior flour of this series was No. 17, with an extensogram area over 1200, and decidedly above the other spring wheat samples.

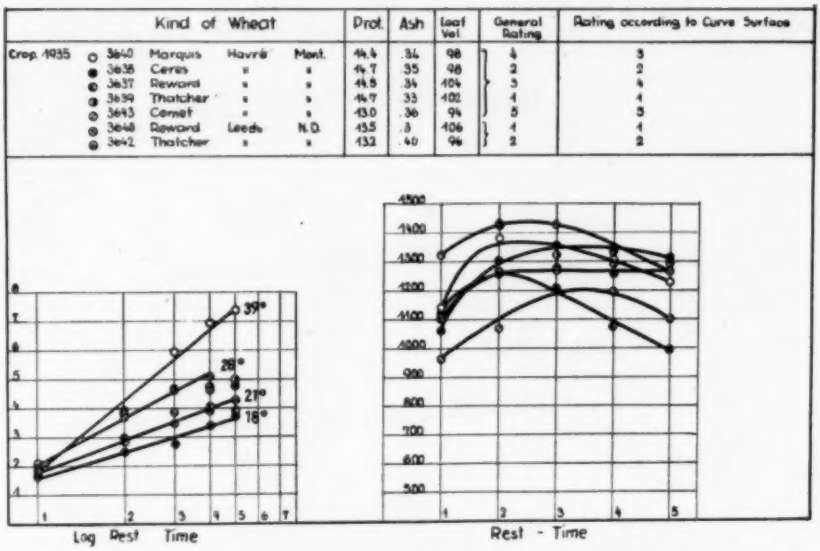
Kind of Wheat
Prot.
Ash
Loaf Vol.
General Rating
Rating according to Curve Surface
Crop 1935
3640 Marquis Havré Mont. 14.4 .34 98 4 3
3638 Ceres " " 14.7 .35 98 2 2
3637 Reward " " 14.8 .34 104 3 4
3639 Thatcher " " 14.7 33 102 1 1
3643 Comet " " 13.0 .36 94 5 5
3648 Reward Leeds N.D. 13.5 .8 106 1 1
3642 Thatcher " " 13.2 .40 96 2 2
39°
28°
21°
18°
Log Rest Time
Rest - Time

Fig. 17. Extensogram data and results of baking tests of the series of flours subjected to test by the Northwest Crop Improvement Association.

Of the two Kansas flours, G.M. 13 and 14, the latter appeared from the farinograms to have been milled from damaged wheat. That No. 14 was inferior to No. 13 was further evident from the area under its extensogram which was about 300 units less than the latter.

Action of Agene bleaching treatment on the Nebraska winter wheat flour No. 15 was significant. The farinograms of the untreated and treated flours, shown in Figure 14*a*, were not greatly dissimilar, but the data from the extensograms in Figure 16 were very different. To begin with, this flour had been milled at least eight months before the Agene treatment was applied. Its oxynumber at that time was only 17, which constituted a basis for predicting a negative response. This prediction was supported by the extensograms, which showed a higher F/E ratio, and a smaller area for the treated flour, after the doughs had rested for several hours. Obviously the extensograms were more useful in testing for response to such treatments than the farinograms.

A series of flours produced in a semi-commercial experimental mill from several wheat varieties grown in the northwestern United States became available for tests. These flours had been subjected to extensive collaborative baking tests under the supervision of the Northwest Crop Improvement Association, with the average results shown in the tabulation at the top of Figure 17. While the farinograms of these seven flours were of interest, they constitute a less satisfactory indication of baking quality than the extensograms, and are omitted from this paper.

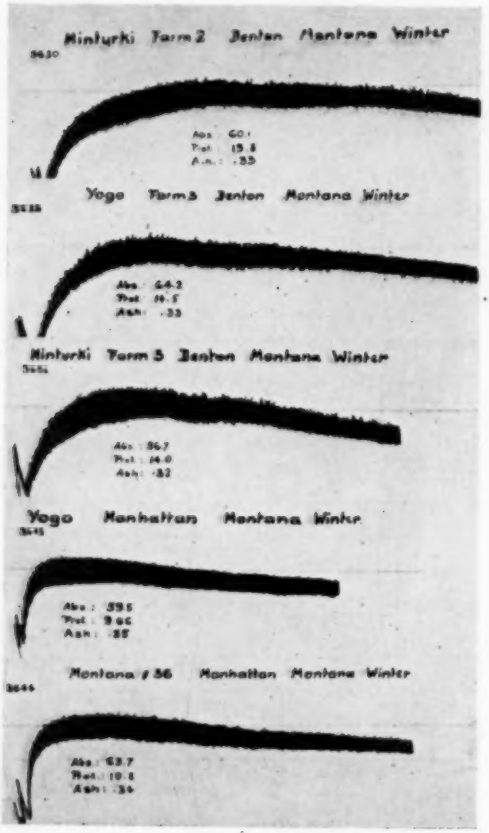
Minturki Farm 2 Denton Montana Winter
Yago Farm 3 Denton Montana Winter
Minturki Farm 3 Denton Montana Winter
Yago Manhattan Montana Winter
Montana # 36 Manhattan Montana Winter

Fig. 18. Farinograms of five Montana winter wheat flours.

Kind of Flour		Prot	Ash	Loaf Vol	Baking Character Indicated
3630 Minturki	Denton #2 Mont	13.8	33	102	Very Good Results
3663 Yago	" #3 "	14.5	33	97	Good "
3652 Minturki	" #3 "	14.0	32	97	good "
3645 Yago	Manhattan "	9.7	35	83	Poor "
3644 Mont # 36	" "	10.8	34	87	Fair "

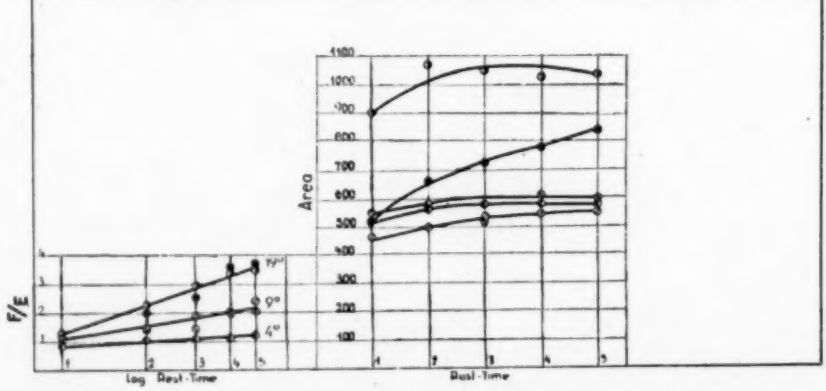

Fig. 19. Extensogram data and baking characteristics of the Montana hard winter wheat flours for which the farinograms are shown in Figure 18.

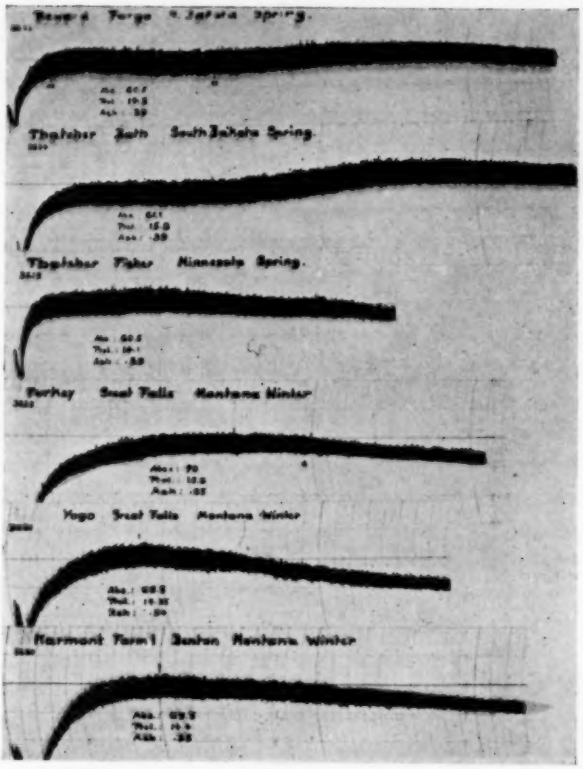
Thatcher Bath South Dakota Spring.
Thatcher Fisher Minnesota Spring.
Turkey Great Falls Montana Winter
Vago Great Falls Montana Winter
Karmont Farm 1 Benton Montana Winter

Fig. 20. Farinograms of the sixth series of hard wheat flour samples.

Crop 1938		Kind of Wheat		Prot.	Ash	Loaf Vol.	General Rating	Extensograph Rating (Area)
○	3632	Reward	Fargo N. D.	14.3	.39	402	Very good	Very large
●	3634	Thatcher	Bath S. D.	15.8	.39	407	" "	" "
◐	3628	"	Fisher Minn.	14.1	.39	401	good	large
◑	3629	Turkey Red	Great Falls Mont.	13.0	.35	86	Fair	medium to small
◑	3651	Vago	" "	13.3	.34	93	"	" "
◑	3680	Karmont	Benton #1 Mont.	14.4	.35	90	"	small

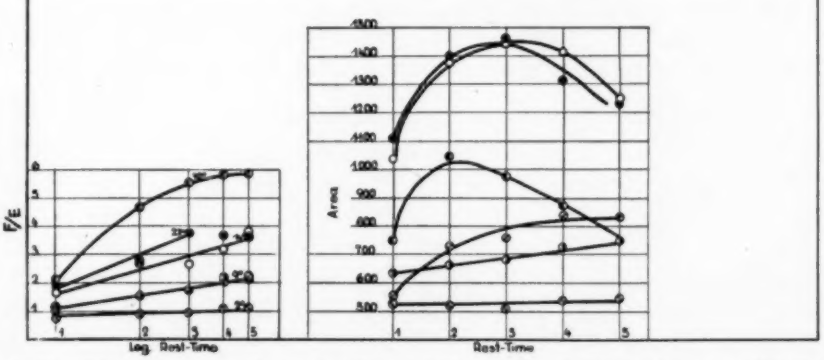

Fig. 21. Extensogram data and general rating of baking quality of the six flours for which the farinograms are shown in Figure 20.

The rating according to the curve surface of the extensograms shown in the right-hand column of the tabulation in Figure 17 correlates closely with the average general rating assigned by the numerous baking technologists who passed judgment upon this series of flours. Unfortunately the available summary of the baking tests does not afford a basis for correlating fermentation tolerance as disclosed by actual tests, with the change in areas under the extensograms as a function of rest time.

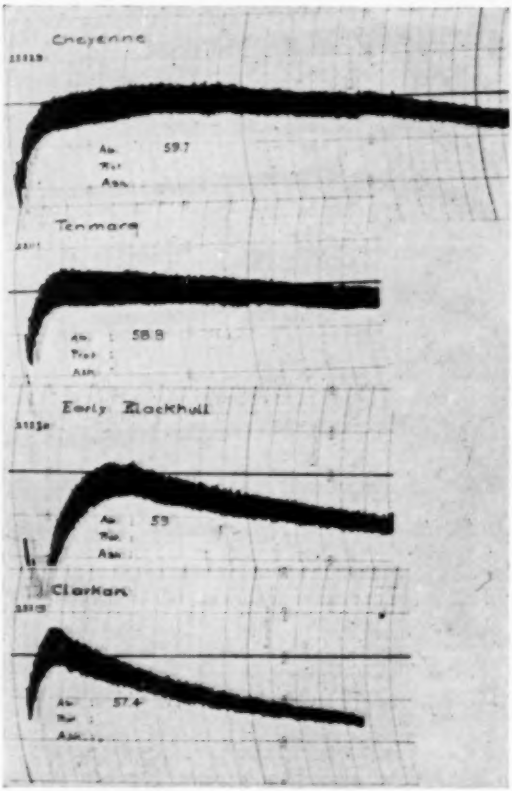

Fig. 22. Farinograms of four Kansas winter wheat varieties.

Five Montana winter wheat flours were used in the next phase of these researches. These had previously been subjected to baking tests with the general results indicated in the last column of the tabulations at the top of Figure 19. Their farinograms are shown in Figure 18, and from them one would predict that Minturki No. 3630 would give the best results in a baking test, while Yogo 3645 would be the poorest of the five. These flours occupied those positions in the baking trials, and, moreover, that is also their relative position in terms of area under the

extensograms recorded in Figure 19. In fact the extensogram data serve again to arrange the five flours in the order of their rating in baking trials.

Still another series of wheat flours, including three milled from hard spring wheats and three milled from hard winter wheats, were subjected to comparative tests. From their farinograms, shown in Figure 20, the Thatcher grown at Fisher (No. 3628) would not be expected to perform as well as the Thatcher from Bath (No. 3634), or the Reward from

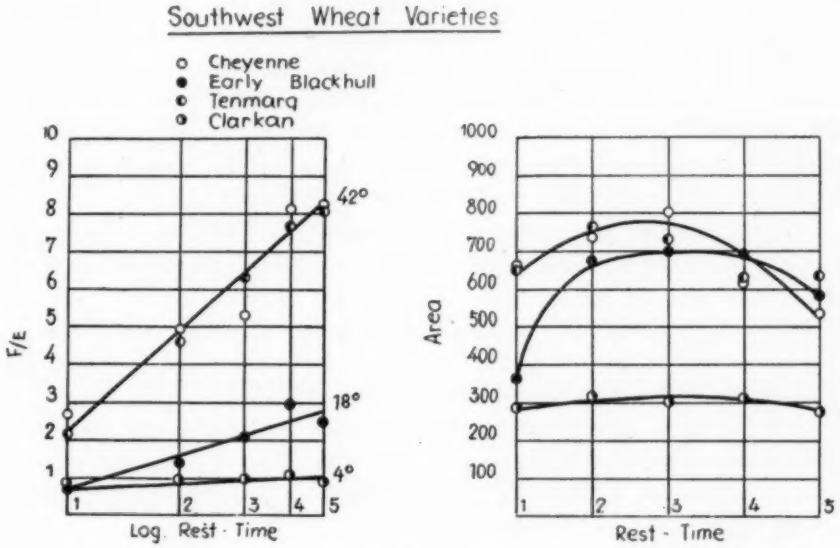

Fig. 23. Extensogram data of the four Kansas winter wheat varieties for which the farinograms are shown in Figure 22.

Fargo (No. 3632), and the cooperating baking technologists of the Northwest Crop Improvement Association rated them in that manner. Reference to the extensogram areas recorded in Figure 21 shows the flours Nos. 3632 and 3634 to be outstandingly high in their curve areas, and very similar to each other, with No. 3628 distinctly lower.

The three winter wheat flours in this series gave farinograms quite different from those of the spring wheat flours. Also the extensogram areas were lower, and the baking tests placed them in the same relation—namely, below the hard spring wheat flours.

Finally, a series of four Southwestern winter wheat flours were compared. It will be noted that the Clarkan sample was in a class by itself, as evidenced by the farinogram, and by the small area under its extensogram, which would serve to rate it as decidedly inferior to the hard wheat flours with which it is here compared.

Summary

Among the soft wheat types the combination of test data derived from farinograms and extensograms serves to classify them as to origin, *i.e.* the class or variety of wheat from which they are milled and as to their adaptability to special uses in baking.

Extensograms are proving singularly useful in disclosing the suitability of flours for cake, cookie, and cracker production. A basis of classification is proposed for use, with emphasis upon the specific form and area under the extensograms, together with other characteristics.

Superimposing lecithin upon untreated cookie flour increased the extensibility of dough made from the mixture, as evidenced by the increased *E* axis of the extensogram. Bleaching with Cl_2 to pH 5.4 had the reverse effect. The combination of chlorine treatment and lecithin restored the properties to approximately those of the untreated flour. Actual cookie baking tests confirmed the extensogram tests.

When hard wheat flours were subjected to tests with the farinograph and the extensograph, it proved possible to correlate the resulting data with the results of baking tests.

Further confirmation was afforded of the usefulness of extensograms in predicting the reaction of hard wheat flours to treatment with oxidizing agents, including Agene and bromate.

On the basis of the experimental evidence reported in the two preceding papers [4] and in this paper it seems that the following generalizations are justified as far as practical deductions from farinograph and extensograph data are concerned:

I. Flour characteristics that can be deduced from the farinogram:

A. Water absorption capacity.

B. General strength (European conception) from
1. Point to optimum development.
2. Rate of consistency decrease after point of optimum development.
3. Curve width.

C. Degree of gluten hardening (shortness).
Indicated by quick development to optimum consistency and optimum curve width. It may be caused by age, heat treatment or varietal influences.

D. Mixing sensitivity: flours that are overmixed easily give
1. Strong curves which show rapid development to optimum curve width and consistency.

[4] See footnotes 2 and 3.

2. Strong curves with very slow development to optimum curve width, the curve width being rather small (bucky flours).
3. Weak curves showing rapid decrease in consistency and curve width.

II. Flour characteristics deduced from extensogram are:
- *A*. Prediction of loaf volume, from area.
- *B*. Bromate response from oxy-number.
- *C*. Fermentation time, from time to reach optimum area.
- *D*. Fermentation tolerance may possibly be deduced from expressions involving
  1. Change in area on extended rest-time.
  2. Change in the ratio F/E as expressed by the angle of the line connecting the different F/E values with the horizontal time axes.
  3. Change in oxy-number on extended rest-time.
- *E*. Deviation from "potential dough properties."
- *F*. Molder tolerance.

THE COUNTING OF YEAST CELLS IN BREAD DOUGHS

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Many uncertainties exist regarding the behavior of yeast in a fermenting dough. Some baking technologists have maintained that yeast does not multiply in a dough, but merely produces leavening gases. Others assert that yeast proliferation takes place. A knowledge of the actual number of yeast cells in doughs when mixed and after various periods of fermentation is of considerable assistance in the scientific study of fermentation problems. The method presented in this communication was developed to study the effect of nutrient salts on yeast growth, but should be of value in the consideration of other problems of fermentation.

Lindet (1910) studied the multiplication of yeast in dough by a plating method. Such methods, however, present difficulties in that yeast cells tend to form clumps, and the counts determined by such techniques are low. Geere and Geere (1922) determined the growth of yeast in doughs by a microscopical method of counting the cells. Simpson (1936) reported a method for counting yeast cells in doughs which was based essentially on the method of Turley (1924). The

principle of this method is the dispersion of the dough with pepsin and hydrochloric acid, the digestion of the starch cells with diastase, the staining of the cells with methylene blue, and counting in the haemacytometer.

The method developed in this laboratory predated the publication of Turley, and has since proved of value over a considerable length of time. It avoids the difficulties of the previously published techniques, and is considerably simpler.

Procedure

Take a 20-gram sample of dough, place in a 2-liter beaker, add 1460 ml. of distilled water, 5 ml. of chloroform, and 10 g. of sodium chloride. The chloroform is added to prevent further growth of the yeast cells while the counts are being made, but, inasmuch as it does not mix with the solution, no account need be taken of it when considering the dilution. The salt is added to bind and hold the gluten in a ball and thus prevent its disintegration during the washing process.

Wash the starch and yeast cells from the gluten by hand for a period of at least 10 minutes, taking care to incorporate all shreds and particles of the original 20-gram sample.

Place the gluten ball in a graduated cylinder and add distilled water to a volume of 500 ml. Again wash the gluten ball in this volume of water for another period of 10 minutes, in order to remove the yeast cells enmeshed therein, and add this solution to the first wash water. Thoroughly agitate this yeast and starch suspension which now totals 1,960 ml., and transfer 49 ml. to a 200-ml. Erlenmeyer flask and stopper to prevent evaporation. Add 1 ml. of standard Carbol Fuchsin solution, made up according to the directions given in the U. S. Pharmacopoeia, to the 49 ml. of the suspension in the Erlenmeyer flask. This gives a final dilution of 20 g. of dough in 2,000 ml. of solution, or a 1-to-100 dilution.

Allow the stained solution to stand four or five hours, or if convenient over night, before the counts are made. This permits the color to stain the yeast cells thoroughly. When examined under the microscope at the end of that period, it will be found that the yeast cells have taken on a deep, dark red color, while the starch cells are only colored a faint pink. Any small particles of gluten material will also be colored a dark red but they can easily be differentiated from the yeast cells because of the regular contour and the cellular structure of the latter. Likewise, it is possible to distinguish yeast cells from small or similarly shaped starch cells by the fact that the latter are always clear and translucent and show no cellular structure.

During the time that the 50-ml. portion of the "starch-yeast" suspension is being stained, place the gluten ball remaining from the

two washings in the graduate and add distilled water to bring the volume to 188 ml., which is about one-tenth the volume of the main suspension. It is better to work with more concentrated solutions in this case because of the very small number of yeast cells still remaining in the gluten ball. Add 0.2 ml. of concentrated hydrochloric acid to the solution and allow to stand over night. At the end of the overnight period the gluten will be dissolved almost completely and upon shaking a colloidal suspension of the gluten is obtained, while the yeast cells are unchanged. To 47 ml. of this suspension add 3 ml. of Carbol Fuchsin solution and let stand over night. It is necessary to use considerably more of the staining solution in this case because the colloidal gluten seems to prevent the yeast cells from readily taking the stain. Even with this amount, the cells are colored only a faint pink, instead of a dark red, as in the case of the "starch-yeast" suspension. However, the minute gluten particles remain colorless in this solution and show no cellular structure.

For this work in our laboratory a Thoma-Zeiss haemacytometer is used, and the counting chamber is a Thoma-Levy modification of the Burker apparatus with two Neubauer rulings. Immediately before the actual counting, the flasks containing the stained solutions are shaken vigorously to bring into suspension all particles and cells which may have settled out. With a stirring rod, drops are removed and one placed on each of the Neubauer rulings and one on the intervening moat. The plano-parallel cover glass is placed in position with the thumb and forefinger and then one end of it is rapidly lifted up and down several times in order to expel any air bubbles and also to insure a uniform distribution of the solution. It is essential that this precaution be taken. The prepared slide is now allowed to set for a few minutes before the counting is started in order that the yeast cells may settle out upon the ruled surface of the counting chamber. The counts are made with the high-power 4 mm. objective.

Each Neubauer ruling of the Thoma-Levy counting chamber is divided into nine large squares, each 1 mm. square. The number of yeast cells in such a square is counted and an average taken of from 8 to 12 such counts. Since there is a space of only 0.1 mm. between the cover glass and the ruled disc, it is necessary to multiply this average count by 10 to find the number of yeast cells in 1 cu. mm. of the solution. This figure must be multiplied by 1,000 to convert to milliliters, and again by 100 because of the dilution of the solution. Consequently, when the average count is multiplied by 1,000,000 the number of yeast cells present in one gram of the original dough is obtained.

Each of the larger square-millimeter squares in the Neubauer ruling is further subdivided into 16 small squares. One of these small squares

completely covers the field of the microscope when the 4-mm. objective is used. In actual practice, therefore, the number of yeast cells in each such small square is counted and the number put down in its corresponding place in a table representing the larger sq.-mm. square. The sum of 16 such counts gives the number of cells in a sq. mm. It has been found preferable to count the cells in one or not more than two sq.-mm. squares, after which the counting chamber is cleaned and a fresh slide is prepared. This prevents errors due to evaporation of the solution, and it is for this same purpose that a drop of the solution was placed in the moat. In counting, the cells lying on the lines above and to the right are counted, never those on lines below or to the left. Yeast buds mature speedily in the dough into normal cells and exert the same influence on the dough as do the parent cells. For this reason, in counting, each bud that is large enough to be unmistakably recognized as such is counted as a single cell.

An Example of Counting

Each square represents a square millimeter on the Neubauer ruling. Thus, the 16 sets of figures inside the square represent the number of yeast cells in the 16 small divisions into which each square millimeter of the ruling is subdivided. Illustrated yeast cell counts follow:

4	2	3	3
6	7	12	11
7	4	7	8
6	7	5	7

Total 99 per sq. mm.

7	2	6	1
5	9	8	3
8	6	10	4
3	7	5	5

Total 89 per sq. mm.

4	4	8	4
6	2	7	4
6	8	3	10
4	3	7	4

Total 84 per sq. mm.

TABLE I

NUMBER OF YEAST CELLS IN SQUARE MILLIMETERS OF NEUBAUER RULING "STARCH-YEAST" SUSPENSION [1]

Individual Counter No. 1	Individual Counter No. 2
No. of cells	*No. of cells*
99	106
89	89
84	83
87	81
124	96
90	87
110	74
85	113
104	113
103	127
91	107
123	99
Average 99.1	98.0
Average of both counters: 98.5 per sq. mm.	

[1] It might be pointed out that two individual counters obtained remarkably close checks on their average total counts, as for example: 92.7 and 92.0, 33.3 and 35.8, 204.0 and 203.6, 52.3 and 52.5, 98.1 and 98.0.

Calculation of Number of Yeast Cells per Gram of Dough

The total number of yeast cells per gram of dough is obtained by adding the number of yeast cells found in the "starch-yeast" suspension and the number found in the "gluten-ball" solution. Since the "gluten-ball" solution is made up ten times more concentrated than the "starch-yeast" suspension, the count on the "gluten-ball" solution is divided by 10 before being added to the count obtained from the "starch-yeast" suspension. For example, if 98.5 cells per sq. mm. were found in the "starch-yeast" suspension, and 18.8 cells per sq. mm. in the "gluten-ball" solution, the total count would be 98.5 plus 1.88, which is 100.4 cells per sq. mm. Multiplied by 1,000,000 the result is 100,400,000 yeast cells per gram of dough.

Accuracy of Method

In order to check the accuracy of this method of counting yeast cells in doughs, a number of doughs were set in which the quantity of yeast was unknown to the persons making the counts. Since yeast in the form of compressed yeast varies in the number of cells per unit weight, it was necessary to determine by counting the number of cells per gram of the compressed yeast in order to make the necessary calculations.

TABLE II

THE ACCURACY IN THE DETERMINATION OF THE QUANTITY OF YEAST IN DOUGHS BY COUNTING THE YEAST CELLS [1]

Type of dough	Cells per gram of compressed yeast used	Cells per gram of dough as determined by counting (average of 384 fields)	Percent yeast on basis of entire dough batch	
			Added	Found
	millions	*millions*	%	%
Laboratory	11,129	100.4	0.89	0.90
Laboratory	11,129	111.7	0.98	1.00
Commercial	11,129	95.8	0.86	0.86

[1] In making yeast cell counts on yeast cakes, it was of advantage to use iodine stain instead of Carbol Fuchsin. A suspension of yeast cells in water without other substances being present tended to form clusters in the presence of Carbol Fuchsin but not in the presence of iodine.

It was found that the size and character of the yeast cells varied considerably in different batches of compressed yeast. In some cases the cells were small and immature, in others larger and older; in some cases a large percentage of buds were present, and in others none. As a result, the number of cells per unit weight of yeast varied considerably, and it was necessary in order to calculate the percentage of yeast in an "unknown" dough to know the number of cells per unit weight in the original yeast.

Summary and Conclusions

A method for counting yeast cells in doughs with a high degree of accuracy has been presented.

This technique makes possible the study of the reproduction of yeast in the dough batch and factors that affect the growth. The use

of this method clarifies the uncertainties which have been controversial in nature.

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FACTORS AFFECTING THE GROWTH OF YEAST IN FERMENTING DOUGHS

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The development of a standardized and accurate method of counting yeast cells in doughs, Hoffman *et al.* (1941), has made possible the study of a number of problems concerning the growth of yeast in fermenting doughs. These problems are of both theoretical and practical interest to the baking technologist.

The Effect of Fermentation Time

A test dough containing the following ingredients was set at 80°F.: flour 960 g., water 555 g., sugar 35 g., salt 15 g., condensed milk 25 g., lard 20 g., and yeast 16 g. The yeast content was 1.67% based on the flour, or 0.98% on the entire dough batch. The dough was allowed to ferment at 80°F., and was punched regularly. Counts were made when the dough was mixed and after 2, 4, and 6 hours of fermentation.

TABLE I

EFFECT OF FERMENTATION TIME

	Yeast cells per gram of dough (average of 256 fields)
	millions
When mixed	98.05
After 2 hrs. of fermentation	98.45
After 4 hrs. of fermentation	124.85
After 6 hrs. of fermentation	133.60

The greatest amount of yeast-cell reproduction occurred between the second and fourth hours. This result is in accordance with the rate of gas production as shown in Figure 1.

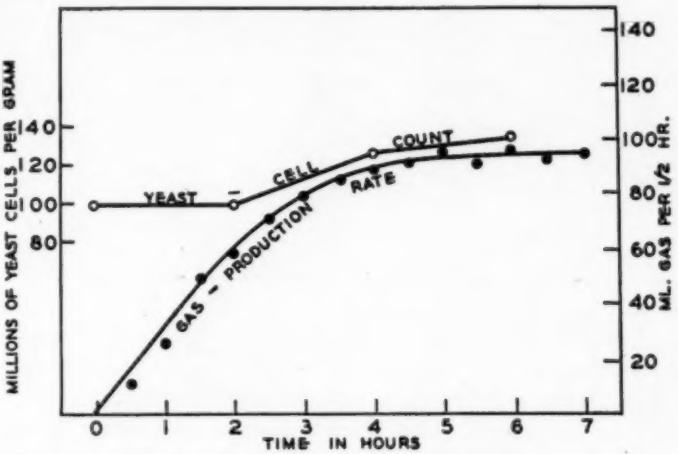

Fig. 1. The relationship of gas-production rate and yeast-cell growth.

The Effect of the Quantity of Yeast

In this determination all variables such as time, temperature, and ingredients other than yeast were held constant as far as possible. The test doughs were used, the temperature maintained at 80°F., and the total fermentation time was six hours.

TABLE II

THE EFFECT OF THE QUANTITY OF YEAST ON YEAST GROWTH

Percent yeast based on the flour	Yeast cells per gram of dough			
	When mixed	After six hours	Increase	Percent increase
%	*millions*	*millions*	*millions*	%
0.5	29.8	56.2	26.4	88
0.75	39.7	64.1	24.4	61
1.00	52.1	82.6	30.5	58
1.25	67.3	101.1	33.8	50
1.50	82.0	122.5	40.5	49
1.75	93.3	135.6	42.3	45
2.00	115.7	149.9	34.2	29

It is interesting to note that the volume of baked loaves followed very closely the actual increase in yeast cells, as shown in Table II. The graphical representation of the relationship between the actual increase in yeast cells and the loaf volume of the resulting bread is given in Figure 2.

TABLE III

EFFECT OF QUANTITY OF YEAST ON LOAF VOLUME

Percent yeast based on flour	Fermentation time			Average loaf volume
	3 hrs.	3½ hrs.	4 hrs.	
%	cc.	cc.	cc.	cc.
0.5	1240	1440	1560	1414
0.75	1280	1470	1560	1437
1.00	1320	1540	1620	1493
1.25	1600	1620	1570	1597
1.50	1640	1640	1680	1653
1.75	1579	1710	1790	1690
2.00	1540	1650	1610	1600

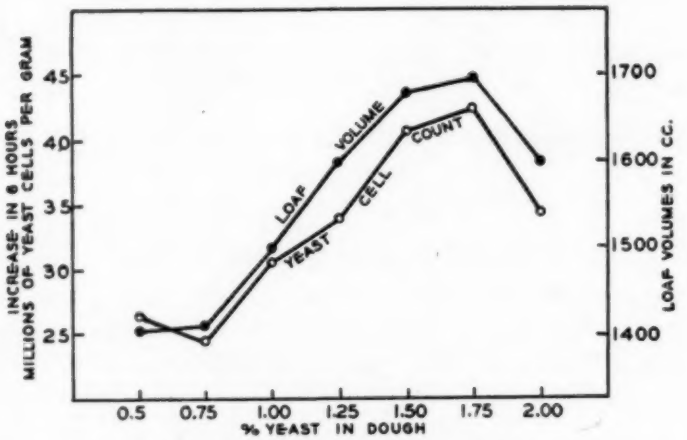

Fig. 2. The relationship between the actual increase in yeast-cell count and the loaf volumes of the resulting loaves of bread.

Lindet (1910) showed that the smaller the quantity of yeast in a dough, the greater the percentage multiplication of cells in the dough. Geere and Geere (1922) also reported that when the quantity of yeast was decreased there was a considerably greater increase in the rate of growth of the yeast. The results given above are in agreement, therefore, with previously published data.

The Effect of Ammonium Chloride and Ammonium Carbonate

The method of yeast cell counting is of special value in studying the effect of mineral salts on yeast growth. Three test doughs were set: (1) control, (2) 0.048% ammonium chloride, and (3) 0.048% ammonium carbonate, with percentages based on the weight of the flour. (The actual quantity of ammonia is very nearly the same in each salt.) The doughs were fermented for six hours at 80°F., the

yeast cells counted, and the doughs panned, proofed, and baked. The resulting loaves were of course overaged, but the differences were still apparent.

TABLE IV

THE EFFECT OF AMMONIUM CHLORIDE AND AMMONIUM CARBONATE ON THE GROWTH OF YEAST AS RELATED TO GAS PRODUCTION AND LOAF VOLUMES

Yeast nutrient	Yeast cells per gram of dough		Total gas produced in six hours	Loaf volumes of baked bread
	When mixed	After six hours		
	millions	*millions*	*ml.*	*cc.*
None	41.25	80.7	997.5	1540
0.048% NH_4Cl	40.0	101.5	1223.5	1670
0.048% $(NH_4)_2CO_3$	39.25	86.5	1187.5	1610

The dough containing ammonium chloride produced the greatest increase in yeast cells, produced the most gas, and the baked loaves were the largest in size. It would seem from this experiment that the ammonium compound as well as the ammonium ion plays a part in stimulating yeast growth.

The Effect of Ammonium Chloride on Yeast Growth when Different Quantities of Yeast Were Used

It has been shown that the greatest percentage of increase in yeast cell count took place when smaller quantities of yeast were used in the dough. This fact may perhaps be explained by the limiting quantity of nutritive material in the dough; and the more yeast present, the less available food material for each yeast cell. Therefore, yeast nutrients may show the greatest effect when the quantity of yeast used is less than normal.

In order to illustrate this point, four test doughs were set. Two contained the regular quantity of yeast with and without ammonium chloride, and two contained 25% less yeast with and without ammonium chloride.

TABLE V

THE EFFECT OF AMMONIUM CHLORIDE ON YEAST GROWTH WHEN DIFFERENT QUANTITIES OF YEAST WERE USED

Percent yeast based on flour	Ammonium chloride	Yeast cells per gram of dough			Percent increase
		When mixed	After six hours	Increase	
%	%	*millions*	*millions*	*millions*	%
1.67	—	98.8	150.7	51.9	52.5
1.25	—	72.1	128.0	55.9	77.5
1.67	0.048	96.9	155.0	58.1	60.0
1.25	0.048	73.5	145.9	72.3	98.5

These results are shown graphically in Figure 3. They illustrate the fact that ammonium chloride exerts its greatest action when smaller quantities of yeast are used.

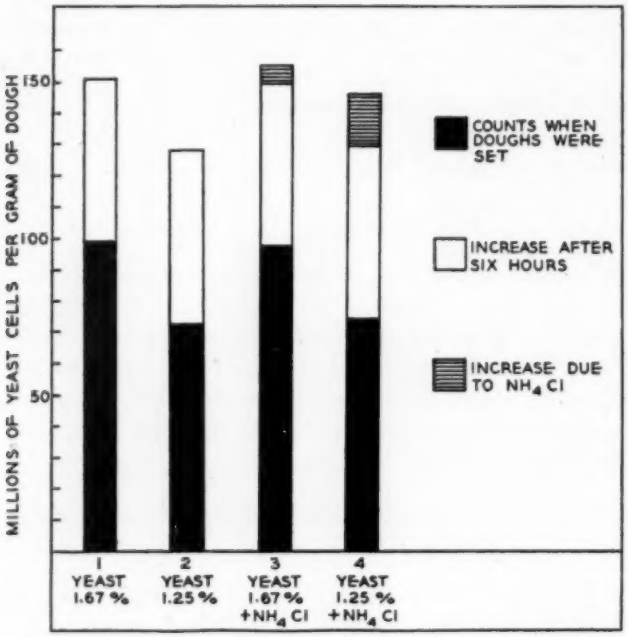
MILLIONS OF YEAST CELLS PER GRAM OF DOUGH
150
100
50
COUNTS WHEN DOUGHS WERE SET
INCREASE AFTER SIX HOURS
INCREASE DUE TO NH_4 Cl
1 YEAST 1.67 %
2 YEAST 1.25 %
3 YEAST 1.67 % +NH_4 Cl
4 YEAST 1.25 % +NH_4 Cl

Fig. 3. The effect of ammonium chloride on yeast growth when the quantity of yeast was varied.

The Effect of Calcium Sulphate on Yeast Growth when Smaller Quantities of Yeast Were Used

As in the case of ammonium chloride, the effect of calcium sulphate was more pronounced when the quantity of yeast was smaller than the regular quantity used in the dough.

TABLE VI

THE EFFECT OF CALCIUM SULPHATE ON YEAST GROWTH

Dough	Percent yeast based on flour	Calcium sulphate	Yeast-cells per gram of dough			Percent increase
			When mixed	After six hours	Increase	
	%	%	*millions*	*millions*	*millions*	%
No. 1	1.67	—	91.6	131.2	39.6	43.2
No. 2	1.50	—	79.2	110.5	31.3	39.5
No. 3	1.50	0.127	78.1	123.1	45.0	57.6

The data given in Table VI were selected for illustrative purposes from a large amount of experimental results. It had been determined

by baking tests that a decrease of 10% in the yeast, from 1.67% to 1.50%, plus 0.127% calcium sulphate (percentage based on the flour) gave finished loaves comparable in quality to the control loaves containing 1.67% yeast.

The Cumulative Effect of Two Yeast Nutrients

Ammonium chloride and calcium sulphate when used separately in doughs increased the rate of yeast-cell reproduction. When these two salts were used together there was a cumulative effect; that is, the effect of the two salts when used together was greater than the sum of the effects of the salts when used separately.

TABLE VII

THE CUMULATIVE EFFECT ON YEAST-CELL GROWTH WHEN AMMONIUM CHLORIDE AND CALCIUM SULPHATE WERE USED TOGETHER

Dough	Percent yeast based on flour	Ammonium chloride	Calcium sulphate	Yeast cells per gram of dough			Percent increase
				When mixed	After six hours	Increase	
	%	%	%	*millions*	*millions*	*millions*	%
No. 1	1.67	—	—	91.6	131.2	39.6	43.2
No. 2	1.50	—	—	79.2	110.5	31.3	39.5
No. 3	1.25	—	—	62.8	98.1	35.3	56.2
No. 4	0.92	—	—	50.6	73.0	22.4	44.3
No. 5	1.50	—	0.127	78.1	123.1	45.0	57.6
No. 6	1.25	0.048	—	59.5	116.4	56.9	95.6
No. 7	0.92	0.048	0.127	47.9	121.7	73.8	154.1

The increase due to calcium sulphate is obtained by subtracting the increase in yeast cells in dough No. 2 from the increase in yeast cells in dough No. 5 (45.0−31.3), giving 13.7 million yeast cells per gram of dough.

The increase due to ammonium chloride is obtained by subtracting the increase in yeast cells in dough No. 3 from the increase in dough No. 6 (56.9−35.3), giving 21.6 million yeast cells per gram of dough.

The additive increase due to both calcium sulphate and ammonium chloride is obtained by adding the increase in yeast cells due to calcium sulphate obtained above, 13.7, and the increase due to ammonium chloride, 21.6, giving 35.3 million cells.

The increase due to the combined action of ammonium chloride and calcium sulphate is obtained by subtracting the increase in yeast cells in dough No. 4 from the increase in dough No. 7 (73.8−22.4), giving an increase of 51.4 million cells. It was shown above that the additive increase was only 35.3 million cells. Therefore the cumulative effect (51.4−35.3) is 16.1 million yeast cells due to the combined action

in a single dough of two yeast nutrients. These results are shown graphically in Figure 4.

The quantities of yeast used in conjunction with the yeast nutrients was determined by series of baking tests. It was found, for example, that 1.50% yeast and 0.127% calcium sulphate (dough No. 5) gave baking results comparable to the control containing 1.67% yeast. Dough No. 6, containing 1.25% yeast and 0.048% ammonium chloride,

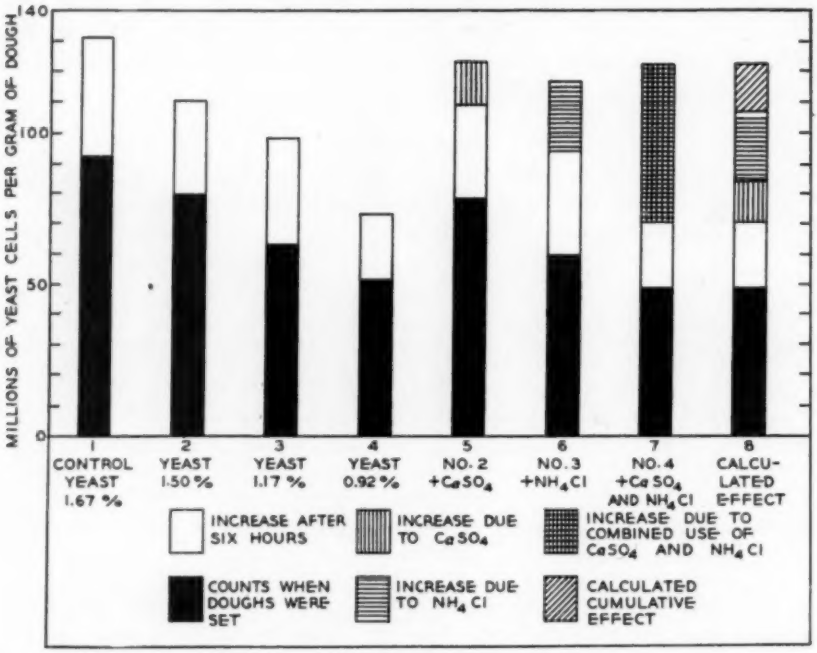

Fig. 4. The cumulative effect of ammonium chloride and calcium sulphate on yeast-cell growth.

produced bread of equal quality to the control. This was also true of dough No. 7, containing only 0.92% yeast and both calcium sulphate and ammonium chloride. The criterion in these experiments was the production of bread equal in quality to the control bread even though differences in amounts of yeast were substantial.

Summary

The following facts have been demonstrated by the method of yeast-cell counting:

1. Yeast definitely grows in the dough batch, the greatest amount of growth occurring between the second and fourth hours in a straight-dough formula.

2. 1.75% yeast based on the flour was found to give the optimum baking results under the conditions of this test.

3. Ammonium chloride was shown to be a better yeast nutrient than the closely related ammonium carbonate.

4. Ammonium chloride exerts its greatest action as a yeast nutrient when smaller quantities of yeast are used.

5. Calcium sulphate shows definite yeast-stimulating properties.

6. Ammonium chloride and calcium sulphate when used together in a dough show a cumulative nutritive effect on yeast.

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1910 Sur le rôle de la levure en boulangerie. Compt. rend. **150**: 802–809.

THE NUTRITIVE VALUE OF THE PROTEINS OF RICE AND ITS BY-PRODUCTS.[1] III. AMINO ACID CONTENT

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In studies of the biological value of the proteins of rice and its by-products, and of the effect of amino acid additions on growth (Kik, 1939, 1940), it was found that at a 5.5% protein level, the proteins of whole rice and those of polished rice had a lower biological value and a higher digestibility than those of rice bran and of rice polishings. Paired feeding experiments with rats showed that cystine, methionine, and lysine supplemented to a slight extent the proteins of whole rice and of polished rice fed at a 5%–6% level. Tryptophane, however, did not have any beneficial effect and cystine did not improve growth of the proteins of rice bran and rice polishings when fed at an 8% level.

Amino acids can be determined quantitatively in foods (Csonka, 1937a, 1937b), and the present investigation was therefore undertaken to determine the amino acid content of the proteins of whole rice, polished rice, rice polishings, and rice bran. Cystine, tryptophane, lysine, arginine, and histidine content were determined. All these amino acids are nutritionally essential, except cystine, which is only

[1] Research Paper No. 671, Journal Series, University of Arkansas. Published with the approval of the Director of the Arkansas Agricultural Experiment Station.

essential when methionine is present in too low a level, and arginine, which can be partly synthesized in the body (Rose, 1938).

Considerable variation has been reported (Csonka, 1937a, 1937b), in the amino acid content of different varieties of wheat. In this paper data are presented on the amino acid content of different varieties of rice. Results are also submitted on amino acid determinations of the proteins of rice grown on plots treated with and without different fertilizers; such a study was included in order to find out to what extent, if any, the composition of the rice proteins could be effected by soil treatment.

Experimental Work and Discussion

Whole rice, white polished rice, rice bran, and rice polish were purchased from a local mill and were of the Supreme Blue Rose variety. Other rice varieties and the rice grown on plots treated with and without fertilizer were obtained from the Rice Branch Experiment Station.[2] These rices were shelled with the aid of a shelling board, cleaned with a fanning mill, and milled to a fine flour.

Preparation of samples.—The samples were prepared as described by Csonka. A short outline of the slightly modified procedure follows: 25 g. of ground material was defatted by three half-hour extractions with 100 cc. of ether. This material was extracted three times for one hour with 1% NaCl solution at refrigeration temperature (6°–8°C.). This removed the water and salt-soluble nitrogen. This was followed by three 60% aqueous alcohol extractions in 100-cc. portions at room temperature, two of two hours' duration and one overnight. Then followed four 0.1% alkali extractions of one hour in 100-cc. portions and at room temperature. These alkali extracts were immediately acidified with dilute acetic acid.

The final extraction was with 100 cc. of a cold 20% HCl solution, the material was placed in the refrigerator for one hour, and stirred occasionally for dispersion of starch. At the end of the hour 150 cc. of 95% alcohol was added slowly with constant stirring for the starch precipitation and this material was centrifuged. This acid alcohol extraction was repeated. To the remaining material 300 cc. of 20% HCl was added in order to dissolve the starch, and later another 100 cc. The residue was hydrolyzed in 100 cc. of 20% HCl in an oil bath for 24 hours. The salt, alcoholic, alkali, and acid-alcohol extracts were combined and evaporated to a small volume on a water bath in evaporating dishes, then transferred to a 300-cc. Erlenmeyer flask. The material was finally hydrolyzed for 24 hours in an oil bath. The amino acids were determined in this hydrolysate, to which was added the hydro-

[2] Located at Stuttgart, Arkansas.

lysate of the residue. The amino acids were determined by methods outlined by Block (1938).

Cystine was determined according to the Sullivan method, and direct methods were employed for the determination of histidine, arginine, and lysine. Histidine was quantitatively precipitated from the amino acid hydrolysate as its silver salt at pH 7.4 Arginine silver salt was precipitated between the pH range of 8.5 to 14.0, and lysine was precipitated by phosphotungstic acid from a solution containing 5% by weight of H_2SO_4. Tryptophane was determined according to the method of May and Rose as modified by Csonka (1937a and 1937b).

The distribution of nitrogen in the extracts included from 90% to 93% of the total nitrogen as can be seen from Table I. The salt-

TABLE I

NITROGEN EXTRACTED BY VARIOUS SOLVENTS, INDICATED AND EXPRESSED IN PERCENTAGE OF TOTAL RICE NITROGEN

Solvent	Whole rice	White rice	Rice from sulfur-treated plot	Rice from check plot
	%	%	%	%
1% NaCl	13.82	11.51	16.20	14.53
60% alcohol	3.66	5.75	4.00	3.00
0.1% alkali	44.22	40.85	40.00	40.00
Acid alcohol	3.98	5.33	4.70	3.70
Residue hydrolysate	25.90	27.60	28.50	32.00
Total yield	91.58	90.50	93.40	93.23

soluble type of protein constituted about 14%, the alcohol-soluble protein 4%, and the alkali-soluble up to 44%. The analytical results are given in Tables II, III, and IV.

Table II shows that whole rice and polished rice are not lacking in cystine, but they do have a low cystine percentage as compared to

TABLE II

TOTAL NITROGEN, AMINO ACID CONTENT AND MG. OF INDICATED AMINO ACID PER GRAM OF TOTAL NITROGEN IN WHOLE RICE, POLISHED RICE, RICE BRAN, AND RICE POLISHINGS, WITH CASEIN, CORN, AND WHEAT FOR COMPARISON

Material	Total nitrogen	Cystine		Tryptophane		Lysine		Arginine		Histidine	
	%	%	mg.	%	mg.	%	mg.	%	mg.	%	mg.
Whole rice	1.23	0.090	73	0.074	60	0.260	212	0.254	223	0.064	52
Polished rice	1.02	0.073	72	0.066	65	0.280	275	0.251	247	0.059	58
Rice bran	2.14	0.137	64	0.096	45	0.443	207	0.344	161	0.090	42
Rice polishings	1.98	0.141	71	0.107	54	0.444	224	0.273	138	0.071	36
Casein [1]	15.00	0.300	20	1.950	130	7.120	475	3.540	236	2.340	156
White corn [1]	1.71	0.096	56	0.047	28	0.107	63	0.212	124	0.089	52
Wheat [1]	2.34	0.157	67	0.080	34	0.872	373	0.356	152	0.080	34

[1] These data are obtained from Csonka (1937 a and b, 1939).

casein and wheat. Rations containing whole rice or polished rice as the only source of proteins do not furnish enough cystine to support good growth and cystine addition has some supplementary effect (Kik, 1940). Tryptophane, arginine, and histidine content compare favorably with the content of those essential amino acids in wheat and corn. The lysine content of whole rice and polished rice, however, is much lower than that of wheat for which a supplementary effect of this amino acid has been reported (Mitchell, 1932).

A decrease of protein occurs in polishings of whole rice as seen by the lower percentage of nitrogen, which is accompanied by a small decrease in cystine, tryptophane, arginine, and histidine content.

From Table III it can be seen that there is considerable variation in the amino acid content of different rice varieties. This corresponds to the observation of Csonka (1937) on the amino acid content of wheat varieties.

TABLE III

INDICATED AMINO ACID PER GRAM OF TOTAL NITROGEN IN VARIETIES OF RICE

Variety of rice	Cystine	Trypto-phane	Lysine	Arginine	Histidine
	mg.	*mg.*	*mg.*	*mg.*	*mg.*
Arkansas 155	95	48	333	214	46
Shoemed	85	70	265	233	66
Arkada	68	69	256	263	37
Zenith	67	55	241	243	54
Fortuna	96	70	317	222	54

In Table IV are shown the results of amino acid determinations of rice grown on plots treated with and without different fertilizers. The rice in each group was of the same variety.

Although small increases were found in total nitrogen in all groups, considerable increases in individual amino acid contents were obtained in some groups.

Group I.—This group consisted of plots 7, 9, 14, and 12 which were treated with superphosphate (at the rate of 250 tons per acre), ammonium sulfate (at the rate of 100 tons per acre), Ammophosko (at the rate of 500 tons per acre), and the check plot (No. 12) which received no fertilizer. The total nitrogen of the rice grown on these plots was 1.38%, 1.30%, 1.31%, and 1.35% respectively. Superphosphate and Ammophosko increased the cystine content from 0.91% to 0.107% and 0.097% respectively, and the tryptophane content increased from 0.067% to 0.086% in the Ammophosko-treated plot and to 0.078% in the plot treated with superphosphate. The lysine percent increased from 0.303% to 0.322% in the Ammophosko-treated plot, to 0.366% in the ammonium sulfate-treated plot and to 0.323% in the superphos-

phate-treated plot. The arginine content increased from 0.256% to 0.352% in the Ammophosko-treated plot and to 0.354% in the ammonium sulfate-treated plot. Histidine was increased from 0.067% to 0.072% in the superphosphate-treated plot.

Group II.—Three plots were compared: Plot 2 received $NaNO_3$ at the rate of 150 pounds per acre and sulfur at the rate of 2,000 pounds per acre. Plot 3 received $NaNO_3$ at the rate of 150 pounds per acre and sulfur at the rate of 4,000 pounds per acre. Plot 4 was the check plot. The cystine content increased in Plot 2 ($NaNO_3$ and sulfur treated) from 0.076% to 0.088% and in Plot 3 ($NaNO_3$ and increased

TABLE IV

AMINO ACID CONTENT AND TOTAL NITROGEN OF RICE GROWN ON PLOTS TREATED WITH AND WITHOUT FERTILIZERS

Plot number and treatment of plot		Cystine	Trypto-phane	Lysine	Arginine	Histidine	Total nitrogen
		%	%	%	%	%	%
			GROUP I				
7	Superphosphate	0.107	0.078	0.323	0.256	0.072	1.38
9	Amm. sulfate	0.092	0.066	0.366	0.354	0.067	1.30
14	Ammophosko	0.097	0.086	0.322	0.352	0.052	1.31
12	No fertilizer	0.091	0.067	0.303	0.256	0.067	1.35
			GROUP II				
3	$NaNO_3$, 4000 S	0.097	0.087	0.305	0.231	0.085	1.35
2	$NaNO_3$, 2000 S	0.088	0.089	0.336	0.295	0.102	1.36
4	No fertilizer	0.076	0.080	0.247	0.276	0.096	1.29
			GROUP III				
11	1000 S	0.076	0.089	0.344	0.290	0.079	1.33
12	2000 S	0.067	0.089	0.374	0.196	0.076	1.35
18	$NaNO_3$, 3000 S	0.066	0.082	0.330	0.329	0.092	1.33
14	$NaNO_3$	0.076	0.080	0.259	0.259	0.077	1.33
19	No fertilizer	0.073	0.079	0.257	0.186	0.085	1.28
			GROUP IV				
27	Manure	0.076	0.075	0.338	0.249	0.080	1.23
29	No fertilizer	0.074	0.070	0.348	0.252	0.077	1.13

sulfur) to 0.097%. The tryptophane content was increased from 0.080% to 0.089% in the second plot and to 0.087% in the third. The lysine content increased from 0.247% to 0.336% in the second plot and to .305% in the third, both treated with $NaNO_3$ and sulfur. The arginine content was changed in the second plot only from 0.276% to 0.295%.

Group III.—This group consisted of five plots, treated as follows: Plot 11 received sulfur at the rate of 1,000 pounds per acre, Plot 12 sulfur at the rate of 2,000 pounds per acre, Plot 18 $NaNO_3$ at the rate of 150 pounds and sulfur at the rate of 3,000 pounds per acre, Plot 14 $NaNO_3$ at the rate of 150 pounds per acre, and Plot 19 was the check plot. The total nitrogen was 1.33%, 1.35%, 1.33%, 1.33%, and 1.28%,

respectively. The tryptophane content was increased from 0.079% to 0.089% in the sulfur-treated plot. The lysine content increased from 0.257% to 0.344% in Plot 11, to 0.374% in Plot 12, and to 0.330% in Plot 18. The arginine content increased from 0.186% to 0.259%, 0.329%, 0.196% and 0.290% in the $NaNO_3$ and sulfur-treated plots.

Group IV.—This last group consisted of two plots, Plot 27 treated with manure at the rate of 500 pounds per acre and the check Plot 29. The total nitrogen increased from 1.13% to 1.23%. The cystine content increased from 0.074% to 0.076% in the manure-treated plot, the tryptophane from 0.70% to 0.75% and the histidine from 0.077% to 0.080%, changes too small to be considered significant.

From these data it is concluded that within the genetic make-up of the variety the composition of rice proteins can be influenced to a certain extent by the treatment of the soil (application of fertilizers).

Summary

Data are presented on the cystine, tryptophane, lysine, arginine, and histidine content of whole rice, polished rice, rice bran, and rice polishings. The amino acid content compared favorably with that for corn, wheat, and casein, except for tryptophane, lysine, and histidine, which were higher in casein. Differences were found in the composition of the proteins of rice varieties. Increases were obtained in cystine, tryptophane, lysine, arginine, and histidine content of the proteins of rice from plots treated with fertilizers (superphosphate, ammonium sulfate, Ammophosko, $NaNO_3$, and sulfur) as compared to the amino acid content of the proteins of rice from untreated plots.

Acknowledgments

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AN ACID-ALKALI METHOD FOR STAINING TRIBOLIUM EGGS IN FLOUR

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Two methods for separating *Tribolium* eggs from the bulk of a flour sample and subsequently staining them were described in an earlier paper.[1] By one of these methods the sample is bolted through a 6XX silk cloth and the eggs are concentrated in the overs, which are then digested with 5% sulfuric acid on a water bath. The digested mixture is filtered in a Buchner funnel, and the residue on the filter paper is treated with iodine solution, staining the eggs a golden- or yellow-brown and the starch and filter paper blue. By the other method the sample is shaken with a chloroform-toluol mixture in a special separatory funnel, and the eggs rise to the surface of the liquid where they may be decanted through a Buchner funnel. The filter paper is stained with iodine as previously noted.

While investigating the use of sulfuric acid as a digestant for flour overs, experiments were also conducted to determine the effects of dilute nitric acid, hydrochloric acid, and sodium hydroxide on *Tribolium* eggs. Sulfuric acid and hydrochloric acid appeared unreactive, whereas nitric acid and/or sodium hydroxide affected the eggs.

The purpose of this report is to present another method for staining *Tribolium* eggs in flour. The method is based upon the color manifested by the eggs after treatment with 5% nitric acid followed by 10% sodium hydroxide.

Effects of Acids on Overs and Eggs

The eggs used in these experiments were obtained from cultures of twenty *Tribolium* beetles in 50 g. of hard-wheat patent flour. The flour had previously been bolted through a 6XX silk cloth to remove all material which would not pass through the mesh. The cultures were kept in a darkened incubator for 48 hours before they were examined for eggs. The eggs were separated from the flour by bolting through a 6XX cloth.

To note the effects of acid, a definite number of eggs was transferred to a 250-cc. beaker, 30 cc. of acid was added, and the beaker, covered with a watch-glass, was placed on a boiling water bath for five to ten minutes. The temperature of the liquid in the beaker attained approxi-

[1] B. L. Blumberg and C. W. Ballard, Food Industries 10 (No. 1): 36–38, 1940.

mately 80°C. After digestion, the material was filtered in a Buchner funnel and the eggs were examined before and after staining with iodine solution.

Tests conducted with 5% nitric acid, 5% hydrochloric acid and 5% sulfuric acid indicated that none of the acids destroyed the eggs, although after the nitric acid digestion and iodine stain the majority of eggs assumed a red-brown color (rather than the pale yellow produced by sulfuric acid or hydrochloric acid digestion), and the flour residue on the paper was more yellow-brown than blue or blue-brown. This, of course, interfered with the differentiation of the egg.

Effects of Sodium Hydroxide on Overs and Eggs

Tests paralleling those described above were carried out to determine the effects of varying concentrations of sodium hydroxide. The alkali tended to destroy the eggs rather quickly even in small concentrations. It was not possible to recover all of the eggs in a test when using only 1% sodium hydroxide at 80°C. for five minutes. Moreover, the alkali caused the flour to gelatinize during the digestion process, thus rendering filtration very slow.

Effects of Acid Followed by Alkali

While experimenting with the use of acid followed by alkali for digesting the overs, it was noted that eggs treated with nitric acid and then sodium hydroxide turned a distinct orange-red. Since the eggs could be fairly easily seen and the method was simple, this reaction was investigated more throughly in order to establish another procedure for staining *Tribolium* eggs.

The Acid-Alkali Method for Staining Tribolium Eggs

After a large number of trials under various conditions, the following acid-alkali procedure was found suitable for staining *Tribolium* eggs in patent wheat flour.

A small quantity (0.1 — 0.6 g.) of sample was placed in a glazed white porcelain crucible cover of 5 cm. diameter and 6–7 mm. depth. The sample was obtained by taking a small quantity directly or preferably by concentrating the bulk of a large sample by bolting through a 6XX cloth.

The sample was wetted with 1.5 cc. of 95% ethanol, and 5 cc. of 5% nitric acid (5.2 cc. conc. nitric acid plus 94.8 cc. dist. water) was added. Using a glass rod which had been flattened and bent at an angle at one end, the mixture was stirred thoroughly and the container, covered with a glass plate, was placed on a boiling water bath.

The mixture was heated on the bath for 7 to 8 minutes, removed, and then 3 cc. of 10% sodium hydroxide (w/v) was added. Using the glass rod, the alkali was thoroughly mixed with contents of the cover, and the liquid was then observed for the presence of opaque, orange-red, ovate structures. Occasionally, a low-power hand lens aided in the detection of the eggs and their differentiation from artifacts.

After the nitric acid digestion the liquid was yellowish, and upon addition of the alkali it turned yellow-orange. Undigested starch clumps appeared yellow to orange-red, but these were usually well dispersed in the final stirring and offered little difficulty. Bran particles, being normally yellow to brown in color, sometimes interfered. In doubtful cases, it was remedial to empty the contents of the crucible cover into a 9 cm. petri dish which was placed on a sheet of white paper and examined under a strong light. In this way the artifacts became almost invisible and the only readily apparent structures conforming to the description noted above were the eggs.

The starch and bran were also differentiated from the eggs by staining procedures. Thus when the contents of the crucible cover were filtered in a Buchner and the excess alkali was removed by washing, the starch, upon the addition of 1% aqueous iodine solution, turned blue. Similarly, when the material in the Buchner was covered with Ehrlich's triacid stain for about 30 seconds and the excess stain was removed by washing with water, the wheat hairs and many of the bran particles stained a distinct green. These observations were made by spreading the filter paper on a glass plate and examining it with the compound microscope (100 ×) using transmitted light. In a limited number of experiments, the green coloration was helpful in distinguishing between bran tissues and foreign matter.

In the initial stages of this investigation, it seemed that the nitric acid and sodium hydroxide alone were capable of staining the eggs. At this time, however, it is thought that the flour itself also influences the reaction. Every time that the acid-alkali procedure was used in the presence of as little as 0.1 gram of flour, all of the eggs stained. In the absence of flour, the staining reaction was variable and occasionally only two or three of the five eggs stained. Until more data are obtained on the factors involved in this staining phenomenon, it seems advisable to conduct the test in the presence of at least 0.1 gram of flour residue.

Summary

The effects of dilute acid and alkali on *Tribolium* eggs have been noted and an acid-alkali staining procedure has been detailed. This procedure should be considered as a preliminary test which in certain re-

spects is simpler and more expedient than either of the iodine staining tests formerly devised.

Of the three methods—acid digestion, flotation, acid-alkali treatment—for staining *Tribolium* eggs in flour, the first probably will be found the most satisfactory for routine use on finely milled flours. When the acid-alkali procedure is used, the Buchner filtration and the addition of iodine solution are eliminated, but the results may not always be so readily interpreted by the inexperienced observer.

STUDIES IN FLOUR GRANULARITY

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The effect of the degree of fineness of flour on flour quality and its suitability for various purposes has not been studied as much as the subject would seem to warrant. One reason for this is the difficulty in measuring accurately flour granularity and thus in differentiating between flours of slightly different degrees of fineness which might nevertheless have an effect in breadmaking and other processes.

The difficulty of making such measurements was discussed by Kent-Jones, Richardson, and Spalding (1939), who suggested a simple technique for making such measurements. The technique suggested had been used for determining soil particle size and is based upon the application of Stokes' law. It was not claimed that the idea was original, as Gründer (1932) and others had suggested a similar method, but the actual procedure suggested was found to be extremely useful and one which could be easily applied to routine work.

A uniform suspension of a small quantity of flour, such as one gram, in about a litre of petroleum, the physical constants of which, such as specific gravity, viscosity, etc., were known, is made and allowed to settle. The decrease in the cloudiness of this dilute petroleum suspension of flour is measured at a fixed depth by the increase in the intensity of a focused beam of light which shines through the suspension and thus falls on a photoelectric cell. This is recorded by the rise in a galvanometer reading.

For full details of the method, the paper quoted should be consulted. It is not suggested that the results are absolute and there is evidence to suggest that they are somewhat empirical in nature. For instance, in the apparatus used, the distance between the top of the petroleum and

the beam of light is 15 cm. Theoretically this distance might be anything convenient and it should not affect the final results. In practice, if a different depth is used, slightly different results are obtained. A number of factors have to be considered, such as whether Stokes' law can be applied in such circumstances, the effect of the petroleum on the flour, the influence of temperature, etc. The work which has been done with this method, however, suggests that errors introduced by these variations are not serious.

The main point is that in actual commercial experience the results have proved to be particularly illuminating and typical results on flours obtained by this method are given in this paper. In dealing with the sizes of flour particles, there is a fairly narrow range and what is wanted is some method for differentiating within this range. If, for example, the sizes of coarser particles, such as semolina, were wanted, it would be necessary to use a liquid other than petroleum in which to suspend and settle the solid material.

Experimental Results—British-Milled Flours

As Kent-Jones, Richardson, and Spalding (1939) have pointed out, the effect of climatic conditions unfortunately renders ordinary sieving tests on flour unreliable, as the same flour will dress through differently from day to day according to the temperature and relative humidity of

TABLE I

SEDIMENTATION VS. SIEVING TESTS

	211–152 μ	152–124 μ	124–89 μ	89–66 μ	66–25 μ
	%	%	%	%	%
	SAMPLE I				
Sieving test	0.5	0.7	7.3	13.5	78.0
Sedimentation method (Kent-Jones, Richardson, and Spalding)	—	—	8.7	17.6	73.7
	SAMPLE II				
Sieving test	0.2	0.3	2.5	9.5	87.5
Sedimentation method (Kent-Jones, Richardson, and Spalding)	—	—	4.2	13.0	82.8

the air. With certain materials which are more crystalline in nature, this difficulty does not arise and then sieving can be done with considerably more accuracy.

An opportunity arose to check out the present method of measuring particle size when an inorganic chemical which was not affected by cli-

matic condition was submitted both to this procedure and to careful sieving with standard sieves. The particle sizes happened to be of similar range to flour, and the results of the two methods are given in Table I. To make this comparison the range in size of the sieving test was worked out and the particle size from our experiment calculated within these groups. The agreement is reasonable and confirms the usefulness and accuracy of the method when used with such a difficult substance as flour.

In routine practice the determination of flour granularity with the apparatus described by Kent-Jones, Richardson, and Spalding is a simple matter.

Stokes' law is given by the equation:

$$V = \frac{(\zeta_1 - \zeta_2)g \times D^2}{18\eta},$$

where V = velocity of the falling sphere
ζ_1 = density of the falling particle (In this case the flour and the difference between different kinds of flour is not serious.)
ζ_2 = density of the liquid—in this case the petroleum
D = diameter of the falling particle
η = viscosity of the liquid, *i.e.*, of the petroleum

Now, if the distance between the surface of the liquid and the beam of the light is h, then

$$V = \frac{h}{t},$$

t being the time taken for a given particle to fall from the surface of the liquid to where the beam of light shines through the liquid.

Hence, combining the two equations we get

$$D = \sqrt{\frac{h \times 18\eta}{(\zeta_1 - \zeta_2)g} \times \frac{1}{t}}.$$

At a given temperature ζ_1, ζ_2 and η are constant so that the equation becomes

$$D = \sqrt{\frac{k}{t}},$$

where k is the constant for the apparatus when flour and petroleum is used at a fixed temperature. In actual practice k is determined once and for all from the constants of the flour and the liquid. Those particles which commenced their travel from the surface of the liquid will be the last of that particular size to pass the beam of the light, and hence it is possible from the equation to construct a table showing the

times at which all particles of a given size will have passed below the light beam.

The apparatus is used at 15° C. and, with the distance from the top of the liquid to the light beam being 15 cm., the value for k is 0.00195.

Hence the equation is

$$D = \sqrt{\frac{0.00195}{t}}.$$

Therefore at any stated time we can calculate D, the diameter of the particles which have passed the beam.

Time in seconds	Diameter of particles in microns
15	114.0
25	88.2
45	65.8
60	57.0
120	40.3
240	28.6
600	18.0

The rise in the galvanometer reading between two times t_1 and t_2, for example, is due to the removal of particles between the sizes indicated by a graph constructed from the above table. In practice, all that it is necessary to do is to multiply the rise in the galvanometer reading by the mean of the diameters in question and the figures obtained will be proportional to the mass of particles within that range. Assuming limits for the largest and smallest particles in the material in question, the relative masses can be expressed as percentages and thus a very useful picture given of the granularity of the material.

An example will make this clear. In the writer's laboratory printed forms exist and all the assistant has to do is to weigh out one gram of flour, see that the temperature, the height of the liquid, etc., are correct, the galvanometer set, the stirring commenced, and then the watch started as the stirring is switched off (Fig. 1).

The form is as shown and an actual result is illustrated. Readings are taken at the times indicated and the differences noted. These differences are multiplied by factors on the sheet (*i.e.*, mean of the particle sizes involved). The products so obtained are added together and the groups expressed as a percentage of the total. The form is so arranged that calculations can be made for obtaining the result in the four groups 105—55 μ, 55—35 μ, 35—25 μ, and 25—15 μ, as well as the percentages above and below 45 μ.

LABORATORY GRANULARITY FORM

Mill . . . . . Date . . .
Flour Kansas 2nd Sizings . . . . . Lab. No. 26574

Time	Gal. Rdg.	Difference x Average Size	% Total	Difference x Average Size	% Total
15 SECONDS 17.5	19.6 17.4				
20 SECONDS SECS.	19.4				
25 Seconds	19.5	1.3 x8.0 = 10.4	31		
30 Seconds	19.3		105 / 55μ	1.9 x7.5=14.3	38 Above 45μ
45 Seconds	18.9				
1 MINUTE	18.3				
1½ Minutes	17.9	1.4 x4.5 = 6.3	19		
2 Minutes	17.3		55 / 35μ		
2½ Minutes	16.9				
3 Minutes	16.3	2.7 x3.0 = 8.1	24		
4 Minutes	15.2		35 / 25μ		
5 MINUTES	14.2				
6 Minutes	12.6			7.9 x3.0= 23.7	62 Below 45μ
7 Minutes	11.8				
8 Minutes	11.5	4.4 x2.0 = 8.8	26		
9 Minutes	11.2		25 / 15μ		
10 Minutes	11.0				
11 Minutes	10.8				
12 Minutes	10.5				
13 Minutes	10.1				
14 MINUTES	9.8				
TOTAL		33.6	100	% 38.0	100%

OPERATOR . . . . . .

Figure 1.

In the original paper of Kent-Jones, Richardson, and Spalding examples of the results obtained with this method on ordinary flours and finely dressed cake flours were given. Since that paper was compiled many hundreds of such particle-size analyses have been carried out, especially on flours which it was suspected might show interesting results from this standpoint. Table II gives some particle-size analyses on national straight-run flours as are at present being made in Great Britain. In Great Britain only straight-run flours may be made and these are milled to a 72% extraction. All the flours in question are ordinary commercial flours made from blended wheats. In this table the results

TABLE II

PARTICLE-SIZE ANALYSES OF VARIOUS STRAIGHT-RUN FLOURS

Mill No.	105–95 μ	95–85 μ	85–75 μ	75–65 μ	65–55 μ	55–45 μ	45–35 μ	35–25 μ	25–15 μ
	%	%	%	%	%	%	%	%	%
1	3	2	6	9	11	10	12	20	27
2	3	6	7	8	12	13	15	23	13
3	4	6	8	10	12	12	12	19	17
4	2	6	11	11	12	11	12	20	15
5	6	5	5	8	12	10	11	20	23
6	4	8	7	7	8	12	12	21	21
7	2	5	5	10	11	12	15	23	17
8	5	4	7	9	10	11	11	18	25
9	3	5	8	12	12	11	12	19	18
10	5	7	8	9	11	12	10	22	16
11	2	5	9	10	12	11	12	24	15
12	5	6	7	13	12	13	12	18	14
13	3	4	6	8	11	11	13	23	21
14	5	11	12	15	14	11	10	16	6
15	6	6	10	14	14	13	9	15	13
16	0	2	7	8	9	10	12	22	30

Mill No.	Greater than 45 μ	Less than 45 μ	105–55 μ	55–35 μ	35–25 μ	25–15 μ
	%	%	%	%	%	%
1	41	59	31	22	20	27
2	51	49	36	28	23	13
3	52	48	40	24	19	17
4	53	47	42	23	20	15
5	46	54	36	21	20	23
6	46	54	34	24	21	21
7	45	55	33	27	23	17
8	46	54	35	22	18	25
9	51	49	40	23	19	18
10	52	48	40	22	22	16
11	49	51	38	23	24	15
12	56	44	43	25	18	14
13	43	57	32	24	23	21
14	68	32	57	21	16	6
15	63	37	50	22	15	13
16	36	64	26	22	22	30

are first given in groups, the limit of which is 10 μ. It was found particularly useful in the paper mentioned also to give the percentage of particles larger and smaller than 45 μ. Since then a greater number of samples have been examined and it has been found that another and more useful method of presenting the results is to give the percentage masses of particles between the following four groups: 105—55 μ, 55—35 μ, 35—25 μ, and 25—15 μ.

In Table II 16 such flours are given and it will be seen that there are some interesting variations. A few notes on these flours may be of particular interest. Mill No. 1 shows a comparatively small number of

larger-size particles (particularly the 105—55 μ group) and a comparatively large number of the smaller-size particles, 25—15 μ. There is evidence in this mill of overgrinding which results in the flour yielding a thirsty but "dead" and inelastic dough. Mill No. 2 may be taken as a typical or average mill and it will be seen that the results are very similar to mills No. 3, 4, 7, 9, 10, 11, and 12. All these mills produce normal flours. It was suspected that Mill No. 5 had a tendency to overgrind and this is revealed by the nature of the flour produced. The particle size analysis tends to confirm this suspicion of overgrinding as there is a comparatively high percentage of particles in the 25—15 μ group.

On the other hand, mill No. 6 has a rather high percentage of small sized particles but the flour always gives a pleasingly elastic dough and shows no tendency to the "dead" type of dough usually associated with overground flour. Mill No. 6 happens to be a new mill with a large amount of roller surface. Mill No. 8 is very similar in dough characteristics to Mill No. 6—*i.e.*, is completely satisfactory—and the particle size distribution is not unsimilar. The same applies to mill No. 13, which is possibly the most up-to-date and newest mill erected in Great Britain. The result from this mill particularly indicates that it cannot be assumed that, because there is a compartively low number of large size particles (105—55 μ) and a tendency towards a high percentage in the smallest-sized group, there is indication of over-grinding.

Mill No. 14 is particularly interesting as the flour is so coarse, but this is a mill which grinds only a mixture of Manitoba and Yeoman wheat. The latter wheat breaks down in the mill in a similar granular way to Manitoba. The same applies to some extent to mill No. 15, both of them being country mills.

Mill No. 16 is interesting and would certainly seem to show overgrinding. This is believed to be the case, but it is not an English mill—actually it is situated in Africa.

These results are not conclusive, but a small percentage of particles in the largest size group and a large number in the smallest size group may, and often does, indicate overgrinding damage with consequent ill effects on the baking quality. It is possible, however, to have conditions approaching this particle size distribution with new mills of long surfaces, the flour of which does not have these defects. With normal average mills, however, such a particle size distribution would be looked upon with suspicion.

Table III gives some results with individual flours from reduction rolls and, as examples, the flours from the *A*, *B*, *C* and *D* reduction rolls are given from a number of different mills. It is necessary to

TABLE III

GRANULARITIES OF FLOURS FROM REDUCTION ROLLS

Mill No.	Above 45 μ	Below 45 μ	105–55 μ	55–35 μ	35–25 μ	25–15 μ
	%	%	%	%	%	%
		FLOUR *A*				
2	39	61	27	23	19	31
17	37	63	28	20	19	33
18	46	54	35	22	25	18
I	40	60	30	21	18	31
II	36	64	27	19	23	31
III	39	61	30	20	23	27
		ENGLISH WHEAT				
I	33	67	28	18	25	29
II	41	59	31	18	17	34
		MANITOBA WHEAT				
II	65	35	52	25	11	12
III	58	42	48	22	17	13
		FLOUR *B*				
2	53	47	42	22	19	17
17	42	58	31	22	18	29
18	52	48	42	21	23	14
I	47	53	36	21	11	32
II	46	54	38	18	21	23
III	56	44	45	22	18	15
		ENGLISH WHEAT				
I	33	67	28	18	25	29
II	41	59	31	18	17	34
		MANITOBA WHEAT				
II	65	35	52	25	11	12
III	58	42	48	22	17	13
		FLOUR *C*				
2	53	47	40	22	18	20
2 (Another sample)	59	41	48	21	13	18
17	57	43	47	20	13	20
	56	44	45	25	17	13
		FLOUR *D*				
2	39	61	26	31	25	18
18	65	35	51	25	12	12
I	65	35	51	25	13	11
II	46	54	32	26	19	23
III	82	18	68	23	6	3
		ENGLISH WHEAT				
I	48	52	31	32	15	22
II	30	70	22	19	23	36
		MANITOBA WHEAT				
II	58	42	40	33	13	14
III	53	47	35	34	19	12

remember how these particular flours are made. Flour *A* is obtained by the reduction of clean coarse semolina—possibly termed "first midds coarse" in America obtained from the purifiers fed from the early break rolls. *B* is obtained from the fine and clean semolina (first midds fine) from the same purifiers. The feed to *C* roll is mainly the dunst sheets from *A* and *B* flour centrifugals mixed sometimes with fine middlings, *i.e.*, very fine clean semolina. Flour *D* is more often than not obtained by reducing the dunst sheet of *C* together with some fine middlings.

With *A* flour, six mills are given, three of them (Roman letters) being taken from the previous paper. Where necessary, the particle sizes into the four group divisions are recalculated. These results are given so that later comparison can be made with certain American mill streams. With normal mixtures there is very little comment, except that mill No. 18 is distinctly coarser than the others. Illustrations are given of the particle sizes of *A* flour when certain mills were grinding either all English wheat (very soft), or all Manitoba.

The results of *B* flour show this flour to be distinctly coarser than *A*. Again mill No. 18 has a particularly small number of particles in the smallest size group. The same difference between English and Manitoba is clearly seen.

C flour calls for no special comment, but again mill No. 18 tends to have a particularly small percentage of the smallest size group.

With respect to *D* flour, marked variations are observed and this is typical of the flours lower down the mill. Much will depend upon the particular way of grinding the mill in question has, and it is, therefore, suggested that such determination of particle size might be extremely useful in checking up the routine work of mills and in comparing the running of different mills in, for example, one large group, provided, of course, they were working on similar wheats. There is a fairly marked difference in the case of the Mills I and II grinding English wheat. A study of these results confirms that the division into the two groups larger and smaller than 45 μ is not as helpful in differentiating as the four divisions which are now normally employed.

Results with American-Milled Flours

The writers hoped to receive in time for this communication the various flour streams of a Continental mill, but, owing to war disturbances, this has not been possible. Thanks, however, to the courtesy of American confreres a series of American flours of three types, Kansas, soft, and spring, has been submitted to this method of particle size analysis and the results are given in Table IV.

TABLE IV

GRANULARITY TESTS ON SAMPLES RECEIVED FROM GENERAL MILLS INC.

Sample	Lab. No.	105–55 μ	55–35 μ	35–25 μ	25–15 μ	Above 45 μ	Below 45 μ
		KANSAS					
1st midds fine	Z1.5740	29	26	23	22	36	64
1st midds coarse	5741	29	22	23	26	34	66
2nd midds coarse	5742	30	23	23	24	37	63
2nd stream from 2nd midds	5743	40	25	24	11	54	46
3rd midds	5744	32	23	23	22	40	60
4th midds	5745	58	24	12	6	70	30
5th midds	5746	50	25	15	10	63	37
6th midds	5747	37	26	22	15	52	48
7th midds	5748	39	32	19	10	56	44
Break midds	5749	40	25	24	11	56	44
1st break	5750	16	20	32	32	23	77
2nd break	5751	12	21	32	35	20	80
3rd break	5752	24	23	28	25	30	70
Fine first tailings	5753	41	21	18	20	48	52
1st grade low tailings	5754	29	32	20	19	43	57
1st sizings	5755	24	21	29	26	30	70
2nd sizings	5756	31	19	24	26	38	62
Stone stock	5757	65	17	12	6	72	28
Good suction	5758	19	17	23	41	30	70
Rescalp reel	5759	34	24	21	21	42	58
Kansas wheat flour	5760	43	26	25	6	58	42
		SPRING					
1st midds	5774	34	32	18	16	50	50
2nd midds	5775	31	28	22	19	42	58
2nd stream from 2nd midds	5776	46	23	18	13	57	43
3rd midds	5777	23	29	25	23	34	66
2nd stream from 3rd midds	5778	22	18	25	35	30	70
4th midds	5779	37	36	14	13	57	43
5th midds	5780	50	28	12	10	66	34
6th midds	5781	57	27	11	5	75	25
7th midds	5782	50	34	9	7	74	26
1st break	5783	51	33	11	5	69	31
2nd break	5784	32	27	28	13	49	51
3rd break	5785	29	31	24	16	41	59
1st sizing	5786	32	28	21	19	42	58
2nd sizing	5787	30	27	22	21	42	58
1st stone stock	5788	56	22	15	7	68	32
2nd stone stock	5789	59	25	11	5	77	23
1st one tailing	5790	42	33	16	9	62	38
Coarse one tailing	5791	36	29	19	16	47	53
One low grade	5792	52	25	14	9	72	28
1st scalp	5793	34	23	20	23	42	58
Good suction	5794	13	22	24	41	23	77
Finished spring wheat patent	5795	45	30	9	16	61	39

TABLE IV—*Continued*

Sample	Lab. No.	105–55 μ	55–35 μ	35–25 μ	25–15 μ	Above 45 μ	Below 45 μ
			SOFT				
1st midds	5761	19	16	24	41	22	78
2nd midds	5762	29	18	24	29	34	66
3rd midds	5763	29	22	21	28	35	65
4th midds	5764	37	23	21	19	48	52
5th midds	5765	33	24	18	25	46	54
1st sizing	5766	12	9	29	50	15	85
2nd sizing	5767	4	21	23	52	12	88
1st break lower	5768	9	17	27	47	16	84
1st break upper	5769	7	11	25	57	10	90
2nd break lower	5770	12	17	27	44	14	86
2nd break upper	5771	29	11	20	40	32	68
3rd break upper	5772	9	14	23	54	12	88
Soft wheat flour	5773	13	14	25	48	17	83

Owing to the differences between American and British milling systems it is difficult to make proper comparisons. The author is indebted to Mr. J. Lockwood of Messrs. Henry Simon, Ltd., for the following information. Mr. Lockwood is conversant with both British and American milling systems. He states that while it is comparatively easy to make a comparison between a British and a German diagram, the American is so different that too close a comparison might be misleading In a broad sense, however, the following comparison is suggested:

1st midds fine	= B
1st midds coarse	= A
2nd midds coarse	= B mixed with A (from the third break purifier)
2nd stream from 2nd midds	= Coarse C
3rd midds	= Fine B (from coarse midds purifier)
4th midds	= G (the dunst from the BMR)
5th midds	= H
6th midds	= J
7th midds	= K
Break midds	= BMR
1st break	= 1st break
2nd break	= 2nd break
3rd break	= 3rd break
Fine first tailings	= B2
1st grade low tailings	= L
1st sizings	= Coarse A
2nd sizings	= B2
Stone stock	= Fine C
Good suction	= Exhaust flour

Naturally, the soft flours have, generally speaking, only a small percentage of particles in the large size group and a large number in the small size group, and, in this respect, it is interesting to compare the straight-run flours, namely the Kansas wheat flour (Lab. No. Z.1.5760) with the soft-wheat flour (Lab. No. Z.1.5773) and the spring-wheat flour

(Lab. No. Z.1.5795). Broadly speaking, the difference between the Kansas and the spring patent is not marked.

In general the size distribution of the top-grade flour in the case of the Kansas and spring varieties is not unlike the top reduction rolls in English mills grinding Manitoba wheat, except that there is a tendency toward coarseness in the English mills. The 6% of particles in the 25–15 μ group in the case of Kansas (total flour) is not in line with the results of the various mill streams making up the straight-run flour, but the results are actually those obtained with the samples sent. The same is true of the percentage of particles in the 35–25 μ group in the case of the spring patent (Lab. No. Z.1.5795).

Summary and Conclusions

Numerous mill streams, both British and American, have been submitted to analysis for particle-size distribution by the method suggested by Kent-Jones, Richardson, and Spalding, or at least by the routine way this method has been used in commercial practice. Examples have been given of how useful the application of this test can be in milling practice. The routine performance of the test is extremely simple and the information obtained is presented in a simple way which is of commercial value.

Acknowledgments

The author is indebted to Dr. Amos and to Mr. Martin and Mr. Spalding, of this Laboratory, for help in preparing this paper and to Mr. Lockwood in England and to Drs. C. H. Bailey, C. N. Frey, and Quick Landis in America for their cooperation.

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THE INFLUENCE OF TEMPERATURE, MOISTURE, AND GROWTH TIME ON THE MALTING QUALITY OF FOUR BARLEY VARIETIES [1]

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The regulation and control of the environment during malting and the varietal response of barley to such conditions are important from the standpoint of obtaining desired types of malt and efficiency in plant operations. A thorough study of different malting conditions would require a very large number of samples, because so many combinations of environmental conditions may be obtained. Temperature during steeping and malting, moisture content of steeped and germinating barley, and the period of growth may be studied in numerous combinations. The results reported in this paper deal only with conditions that were held constant throughout the malting process. For example, when lots were malted at a prescribed moisture, they were held as constant as experimental technique would permit. If a barley was steeped to a high moisture content, it was maintained at this high level throughout the growing period. Likewise, when a sample was malted at 16°C. (60.8°F.), it was held at that temperature throughout the prescribed time. The writers do not overlook either the need or the desirability of having variability in these conditions during the malting process; but they do feel that a study of controlled and constant conditions is the first approach to the problem. Furthermore, the interpretation of results obtained would be made more difficult under variable or fluctuating conditions. Nevertheless, the study of fluctuating conditions, changed systematically or periodically, might offer a fuller expression of their influence on malt quality.

Plan of Experiment

The plan of this experiment was to study four barley varieties malted at two moistures (43% and 49%), four growth periods (2, 4, 6, and 8 days), four malting temperatures (12°, 16°, 20°, and 24°C.), and one steep temperature (16°C.). With a series of growth periods and malting temperatures, trends and influences can more readily be discovered and interpreted by the use of such graphs as Figure 1.

[1] Based on cooperative investigations between the Division of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture, and the Wisconsin Agricultural Experiment Station. The Federal WPA has contributed to the research through the University of Wisconsin WPA Natural Science Project. The United States Maltsters Association has cooperated through an Industrial Fellowship grant to the University of Wisconsin.

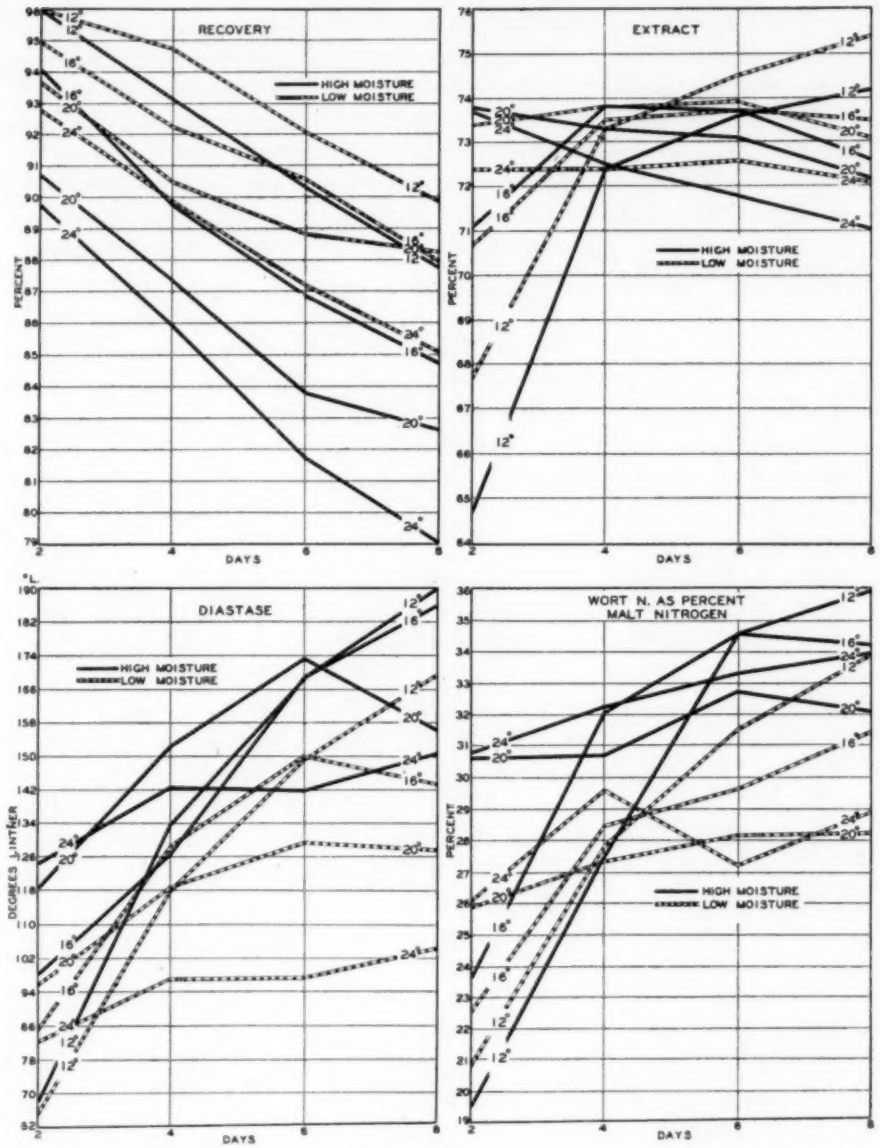

Fig. 1. Influence of malting temperature, moisture, and growth time on the malting quality of four barley varieties. Steep temperature, 16°C.; malting temperature, 12°, 16°, 20°, and 24°C.; moisture 43% and 49% for low (broken line) and high (solid line) respectively; and 2, 4, 6, and 8 days' growth time. *Upper left:* recovery in percent. *Upper right:* extract in percent. *Lower left:* diastase in degrees Lintner. *Lower right:* wort nitrogen as percent of malt nitrogen.

The scope of the experiment was extended at one point by the use of two of the varieties at the additional steep temperature of 12°C. Thus, 32 different combinations of environmental conditions were used for four varieties, and an additional 32 conditions in the case of two varieties where another steep temperature was added. The plan of the experiment may be had in outline from Tables II to XII. Four varieties, of contrasting malting properties, were chosen in order to study their responses to different malting procedures. Environmental conditions and varieties studied in this experiment represent only a small number of those possible.

Materials and Methods

The four varieties used were (1) Oderbrucker (Wisconsin Pedigree 5-1) (C.I. 4666),[2] (2) Wisconsin Barbless (Pedigree 38) (C.I. 5105), (3) Peatland (C.I. 5267), and (4) Chevron (C.I. 1111). The first two varieties have been used in a regional study by Dickson *et al.* (1935) and have been described briefly. Peatland and Chevron are rough-awned, low-yielding barleys imported from Switzerland. Aamodt and Johnston (1935) have described Peatland while Shands (1939) has pointed out the possibilities in using Chevron as a breeding stock. The lot of Oderbrucker barley was produced at the West Hill Farm at Madison, Wis., in 1936. The Wisconsin Barbless barley was grown near Manitowoc, Wis., in 1937. Peatland and Chevron were produced in yield plot trials by B. D. Leith in 1937 at the West Hill Farm. The kernel weights in milligrams, dry basis, for these varieties were 27.62, 25.90, 24.85, and 24.89, respectively. Oderbrucker usually has lower kernel weight than Wisconsin Barbless when grown under similar conditions. The barley nitrogen percentages in the same order were as follows: 2.08, 2.07, 2.28, and 2.49.

The barleys were steeped, germinated, and dried in screen-bottomed cans 5 inches in diameter and 4 inches high. Steeping was done in rectangular pans placed in the malting chamber where the desired temperature was maintained.

The malting chamber consisted of a modified Minneapolis seed germinator equipped with a small fan set to blow against a fine water spray in order to provide circulation of humidified air. Temperature in the chamber was controlled by circulating cold water in the surrounding water jacket, and a thermostated heating bulb within the chamber. The jacket temperature was maintained at approximately 1°C. below the desired temperature and accurate control was accomplished by the heater bulb.

[2] C. I. refers to accession number of the Division of Cereal Crops and Diseases.

The kiln or drier had a capacity of 18 cans on a single shelf. The samples were placed over holes with beveled edges, so that the exhaust fan on the top of the drier produced a movement of heated air through the malt samples. Heat was supplied by several independently operated resistance coils which gave considerable flexibility in temperatures obtainable. Laboratory air was drawn in through holes in the bottom of the drier and passed over the heating elements to acquire the desired temperature, and then up through the malt samples.

TABLE I

THE MOISTURE CONTENT OF STEEPED BARLEY, GREEN MALT, AND DRIED MALT OF FOUR BARLEY VARIETIES MALTED EXPERIMENTALLY

Variety	Malting moisture			
	Low		High	
	16°C. steep	12°C. steep	16°C. steep	12°C. steep
STEEPED BARLEY				
Oderbrucker	42.1	42.9	48.1	47.6
Wis. Barbless	43.7	44.3	48.9	48.5
Peatland	42.7	—	49.0	—
Chevron	42.3	—	49.2	—
GREEN MALT				
Oderbrucker	43.5	43.6	49.6	49.8
Wis. Barbless	43.3	43.5	49.2	49.4
Peatland	43.0	—	49.3	—
Chevron	43.0	—	49.2	—
DRIED MALT				
Oderbrucker	6.7	6.9	6.6	6.7
Wis. Barbless	6.8	7.0	6.8	7.0
Peatland	6.8	—	6.5	—
Chevron	7.0	—	6.5	—

Samples of the barleys weighing 200 g. were placed in the malting cans and steeped at 12° and 16°C. for a number of hours, as determined by a preliminary steep. Approximately 6,400 g. of both Peatland and Chevron were subdivided into 32 lots of 200 g. each by means of a Boerner divider and were stored until used for malting. Oderbrucker and Wisconsin Barbless lots were subdivided by the same means into 64 lots of 200 g. each. After division, each portion was weighed and made to exactly 200 g. At the time of weighing, the moisture contents of barley lots to be malted were 11.6%, 11.6%, 8.9%, and 9.0%

for Oderbrucker, Wisconsin Barbless, Peatland, and Chevron, respectively. After steeping, the lots of barley were drained a uniform length of time, weighed, and placed in the germinator. The germinating barley was stirred twice daily, once after watering and 12 hours later. The placing of the different barley lots into the steep tank was scheduled in such a manner that a series containing 16 malts that had been germinated 2, 4, 6, and 8 days could be placed in the drier at the same time.

In Table I is given the percentage moisture for each variety after steeping to high or low moisture at 12° and 16°C. The time used for steeping at 16°C. was 24 and 60 hours for low and high moisture, respectively, for all varieties. Since the barley varieties were grown under three sets of conditions, it is probably only a coincidence that they absorbed water at approximately the same rate. The percentage for the four varieties averaged 42.7 and 48.8 at low and high moistures when steeped at 16°C. The time used in steeping at 12°C. was 34 and 72 hours, resulting in average moisture contents of 43.6% and 48.1%, respectively. In calculating moisture content out of steep, a loss of 2% and 2.5% in dry weight was estimated to have occurred during steeping for low and high moisture levels.

In these studies, an attempt was made to maintain moistures of about 43% and 49% throughout the growing period. Green malt moistures were slightly above these percentages. In order to maintain the moisture content as planned, it was necessary to anticipate respiration losses and to adjust weights accordingly. These losses were estimated on the basis of data obtained in a series involving 2 to 9 days of malting in the large chamber described by Dickson *et al.* (1938). This series, to be reported later, showed greater respiration losses for Oderbrucker than for Wisconsin Barbless. Little was known of the respiration rates of Peatland and Chevron and therefore estimates were readjusted after the first malting series was completed. To do this effectively, a schedule was outlined for the desired weight of the germinating barley on different days by compensating for loss in weight caused by respiration. Samples were weighed daily and brought to a prescribed weight. Different watering schedules were required for the different malting temperatures. The fact that the moisture content of the green malt agreed closely with the desired value demonstrates that the watering schedule was approximately correct.

The position of the cans in the drier was changed systematically during the period to minimize the influence of slight variations in temperature within the kiln. The temperatures and the times used in drying were approximately as follows: 25°C. at the beginning, which

was raised slowly to 35°C. and held for 24 hours; the temperature was then gradually raised to 45°C. and retained for 4 to 5 hours and finally the temperature was again increased to 55°C. with a finishing temperature of about 65°C. The total time for drying was 33 hours, after which treatment the moisture was near 6.8% as will be seen in Table I. This moisture content was perhaps higher than necessary; but there is evidence to show that higher moisture contents at the end of the drying schedule used are generally more likely to favor maximum expression of certain biochemical factors as will be shown in a later paper.

Physical and Chemical Analyses

The experimentally produced malts [3] were analyzed for the following physical and chemical factors: moisture content of steeped barley and green and dried malt, respiration and steep loss, root loss, recovery of malt from barley, growth of acrospire, kernel weight, extract, diastatic power (in degrees Lintner), malt nitrogen, wort nitrogen (reported as percentage of malt nitrogen), conversion time, and wort color.

Physical and chemical analyses already listed were made on the malts produced experimentally. Growth of acrospire was determined in the conventional manner and growth index calculated as follows:

Length of acrospire	Number kernels	Factor	Index
Dead	x	0	x
0–¼	x	0.25	x
¼–½	x	0.50	x
½–¾	x	0.75	x
¾–1	x	1.00	x
Overgrown	x	1.50	x
Total	x		x

The overgrown group has been arbitrarily multiplied by 1.5. It is realized that not all overgrown acrospires are 1.5 times the kernel length, but such a procedure will serve for making comparisons. Kernel weight on dry basis was determined as described by Shands (1937).

$$\frac{\text{Wt. barley dry basis} - \text{wt. uncleaned malt dry basis}}{\text{Wt. barley dry basis}} \times 100 = \text{respiration and steep loss in percent}$$

$$\frac{\text{Wt. uncleaned malt} - \text{wt. cleaned malt}}{\text{Wt. uncleaned malt}} \times 100 = \text{root loss in percent}$$

$$\frac{\text{Wt. cleaned malt dry basis}}{\text{Wt. barley dry basis}} \times 100 = \text{recovery in percent}$$

[3] The writers acknowledge the assistance of Mr. R. P. Hansen and Mr. L. A. Hunt in this experimental series.

The chemical factors were determined by methods outlined by the American Society of Brewing Chemists. The data obtained for the malting-quality factors discussed have been tabulated for the 192 experimental malts. Some of the results will be presented in detail because this will afford opportunity for the reader to interpret results and form opinions independently of those discussed by the writers.

Respiration and Steep Loss

The method of conducting the experiment did not permit a ready separation of respiration and steep losses; therefore, they are combined in this paper. The detailed results of respiration and steep losses for the four varieties malted under different conditions are given in

TABLE II

THE INFLUENCE OF TEMPERATURE, MOISTURE, AND GROWTH TIME ON PERCENT RESPIRATION AND STEEP LOSS COMBINED, OF FOUR BARLEY VARIETIES MALTED EXPERIMENTALLY

Steep temp., °C.	Malting temp., °C.	Variety of barley	Days of growth and moisture							
			2		4		6		8	
			Low	High	Low	High	Low	High	Low	High
16	12	Oderbrucker	4.2	4.3	2.4	5.2	6.5	6.8	7.6	9.0
		Wis. Barbless	3.4	2.2	3.3	4.1	5.5	5.9	6.8	7.5
		Peatland	3.1	3.7	4.0	4.5	4.8	5.5	7.6	7.8
		Chevron	3.4	3.2	4.1	4.6	4.8	5.9	6.4	7.7
	16	Oderbrucker	4.2	5.6	5.8	8.0	6.5	9.4	8.7	10.7
		Wis. Barbless	3.7	4.0	5.0	6.7	5.5	7.9	7.3	8.1
		Peatland	3.3	4.0	4.7	6.7	5.5	8.1	7.0	8.8
		Chevron	2.9	4.4	4.5	6.4	5.8	8.1	7.1	9.5
	20	Oderbrucker	5.2	6.5	6.8	9.2	8.9	12.1	9.8	13.6
		Wis. Barbless	5.0	5.4	6.1	7.0	7.6	8.9	7.1	9.5
		Peatland	4.3	5.6	5.8	7.3	7.5	9.4	6.9	10.8
		Chevron	4.2	6.1	6.5	7.6	7.4	9.6	8.0	11.5
	24	Oderbrucker	5.5	7.5	7.7	11.4	10.2	16.2	13.3	16.0
		Wis. Barbless	4.5	6.0	5.5	7.9	8.0	10.8	9.5	13.1
		Peatland	4.1	6.1	6.6	7.7	8.1	11.1	9.4	16.1
		Chevron	4.4	6.9	6.7	9.2	8.3	11.5	9.2	12.3
12	12	Oderbrucker	4.7	5.2	5.0	5.8	6.4	7.6	7.4	9.5
		Wis. Barbless	4.1	4.3	4.4	4.8	5.3	6.4	6.4	7.9
	16	Oderbrucker	4.3	4.8	5.8	7.2	6.6	9.0	9.5	11.2
		Wis. Barbless	3.5	3.9	5.0	4.7	5.8	7.0	7.1	8.9
	20	Oderbrucker	5.5	6.4	7.0	9.0	8.6	11.5	11.6	15.8
		Wis. Barbless	4.4	5.0	5.8	6.2	6.1	8.9	9.2	12.0
	24	Oderbrucker	6.4	8.6	9.7	13.1	9.7	14.6	14.4	18.5
		Wis. Barbless	5.2	6.2	7.8	9.4	8.3	10.6	9.0	12.5

Table II. These losses ranged from about 3% in the shorter growth time to about 16% for high-moisture, high-temperature malts grown for the longer period of time. Losses increased with rise in malting temperature for all varieties. While the varieties used were not produced under strictly comparable conditions except for Peatland and Chevron, it is believed that varietal responses have been retained to such an extent that the reactions would change little had the varieties been produced under the same conditions. Even though the main purpose of this paper is to study the influence of such factors as growth time, temperature, and moisture, varietal responses must be carefully considered before conclusions are drawn. The varieties ranked in descending order for respiration and steep losses as follows: Oderbrucker, Peatland, Chevron, and Wisconsin Barbless. The differences between the average values of the respiration and steep losses of the respective varieties were statistically significant with the exception of that between Peatland and Chevron, indicating possible varietal differences with regard to these losses. Even though varieties were different in their average losses from steeping and respiration, it does not necessarily follow that each variety was different from the others under all sets of malting conditions. A summary of the *F* values from the analysis of variance for the several factors studied is given in Table XIII, where it will be seen that interaction values indicate that respiration and steep losses may be influenced by the particular choice of malting conditions. In the discussion of differences in malt quality as caused by variety, moisture, growth time, and malting temperature, as well as first or higher-order interactions, it is well to keep in mind that generalized statements might need modification if applied to a particular set of malting conditions.

Oderbrucker showed greater respiration and steep losses than the other three varieties in practically all cases. At the higher moisture, Wisconsin Barbless gave the lowest losses with Peatland and Chevron intermediate. The loss for Peatland was more between 6 and 8 days' growth than for the three other varieties but intermediate between 2 and 4 days' growth. High moisture caused greater daily losses than did lower moisture, the losses for 8 days at low moisture being approximately equal to estimated losses for 5 days at high moisture. There was little difference in the influence of 12° and 16°C. steep temperatures, the losses being slightly less for the latter temperature.

Root Loss

Root losses were influenced by malting conditions in approximately the same manner as respiration and steep losses, as can be seen from a comparison of Tables II and III. Much more root growth occurred

when either moisture or malting time increased. Increase in malting temperature caused greater root losses with time increase, except for the longer growth periods at 20°C., where the rootlets tended to become brownish. Chevron had greater losses than any other variety, while Peatland was second, with Oderbrucker and Wisconsin Barbless

TABLE III

THE INFLUENCE OF TEMPERATURE, MOISTURE, AND GROWTH TIME ON PERCENT OF ROOT LOSS OF FOUR BARLEY VARIETIES MALTED EXPERIMENTALLY

Steep temp., °C.	Malting temp., °C.	Variety of barley	Days of growth and moisture							
			2		4		6		8	
			Low	High	Low	High	Low	High	Low	High
16	12	Oderbrucker	.4	.8	1.7	2.0	2.7	3.7	3.5	4.6
		Wis. Barbless	.4	.4	1.7	2.0	2.6	3.5	3.2	4.0
		Peatland	.7	.9	2.0	2.5	2.7	3.8	3.3	4.8
		Chevron	.9	.9	2.1	3.0	2.7	4.5	3.2	5.3
	16	Oderbrucker	1.4	1.3	2.7	3.5	4.0	4.9	5.1	6.9
		Wis. Barbless	1.4	1.1	2.8	3.0	3.9	4.7	4.4	5.2
		Peatland	1.6	1.7	2.8	3.5	3.6	5.5	4.7	6.7
		Chevron	1.8	2.2	3.1	4.1	4.0	5.7	5.3	7.4
	20	Oderbrucker	1.6	2.9	3.2	4.8	3.8	7.3	4.2	6.5
		Wis. Barbless	1.6	2.9	3.6	4.7	4.1	6.0	4.2	6.0
		Peatland	1.8	4.7	3.2	5.5	4.0	7.6	3.9	7.0
		Chevron	2.0	4.0	3.5	6.1	4.3	7.5	4.2	7.3
	24	Oderbrucker	2.8	3.6	3.4	6.4	4.3	6.6	3.4	7.7
		Wis. Barbless	2.8	5.5	3.8	5.6	4.6	6.3	5.2	7.6
		Peatland	2.7	3.8	3.7	5.9	4.5	7.0	4.7	7.5
		Chevron	2.7	4.5	4.0	6.3	4.8	6.9	5.4	8.0
12	12	Oderbrucker	.3	.5	1.4	1.9	2.4	2.9	3.4	4.7
		Wis. Barbless	.2	.2	1.6	1.8	2.3	2.9	3.1	4.2
	16	Oderbrucker	1.0	1.1	2.3	3.7	3.5	5.2	3.8	6.0
		Wis. Barbless	1.0	.9	2.3	2.8	3.5	4.7	3.7	5.3
	20	Oderbrucker	1.8	2.8	3.9	6.3	4.8	6.3	5.7	8.0
		Wis. Barbless	2.0	2.6	4.2	5.7	4.4	6.1	5.1	7.8
	24	Oderbrucker	2.3	3.6	3.6	5.4	4.3	8.1	3.4	7.6
		Wis. Barbless	2.5	3.3	3.7	5.2	5.1	6.3	4.8	8.8

third and fourth respectively. In the section of the experiment using two steep temperatures, it was found that malting temperatures, moisture, and time exercised important influences. Oderbrucker root losses were not different from Wisconsin Barbless when a 12°C. steep temperature was used. Regardless of steep temperature, root losses increased with increase in growth time except for the case already noted.

Recovery

The recovery of malt from barley, for each of the experimental maltings, can be considered as the complement of the additive effects of losses of steep, respiration, and rootlets. The data are given in Table IV and portrayed graphically in Figure 1*a*. That recovery

TABLE IV

THE INFLUENCE OF TEMPERATURE, MOISTURE, AND GROWTH TIME ON PERCENT OF RECOVERY OF FOUR BARLEY VARIETIES MALTED EXPERIMENTALLY

Steep temp., °C.	Malting temp., °C.	Variety of barley	Days of growth and moisture							
			2		4		6		8	
			Low	High	Low	High	Low	High	Low	High
16	12	Oderbrucker	95.5	94.9	95.9	92.9	91.0	89.8	89.2	86.9
		Wis. Barbless	96.2	97.5	95.1	94.0	92.1	90.8	90.2	88.8
		Peatland	96.3	95.4	94.1	93.1	92.7	90.9	89.3	87.7
		Chevron	95.8	95.9	93.9	92.6	92.6	89.9	90.6	87.4
	16	Oderbrucker	94.4	93.2	91.6	88.8	89.8	86.2	86.6	83.1
		Wis. Barbless	94.9	95.0	92.4	90.6	90.9	87.7	88.6	87.1
		Peatland	95.2	94.4	92.6	90.0	91.1	86.9	88.6	84.9
		Chevron	95.4	93.5	92.6	89.8	90.4	86.7	88.0	83.9
	20	Oderbrucker	93.3	90.8	90.2	86.5	87.7	81.5	86.4	80.8
		Wis. Barbless	93.4	91.9	90.6	88.7	88.6	85.7	89.0	85.1
		Peatland	94.0	90.0	90.9	87.6	88.8	83.7	89.5	82.9
		Chevron	93.8	90.1	90.2	86.8	88.6	83.6	88.1	82.0
	24	Oderbrucker	91.8	89.2	89.1	82.9	85.9	78.3	83.3	77.6
		Wis. Barbless	92.9	90.7	90.9	86.9	87.8	83.6	85.8	80.3
		Peatland	93.3	90.3	89.9	86.9	87.8	82.7	86.4	77.6
		Chevron	93.0	88.9	89.6	85.1	87.3	82.4	85.9	80.7
12	12	Oderbrucker	95.0	94.4	93.6	92.4	91.3	89.7	89.4	86.3
		Wis. Barbless	95.8	95.5	94.1	93.4	92.5	90.9	90.7	88.2
	16	Oderbrucker	94.8	94.1	92.0	89.3	90.1	86.3	87.1	83.4
		Wis. Barbless	95.6	95.2	92.9	92.7	90.9	88.6	89.4	86.2
	20	Oderbrucker	93.2	91.0	89.4	95.3	87.1	82.9	83.3	77.5
		Wis. Barbless	93.7	92.5	90.3	88.5	89.0	85.6	86.2	81.1
	24	Oderbrucker	91.4	88.1	87.0	82.3	86.4	78.5	82.3	75.4
		Wis. Barbless	92.4	90.6	88.9	85.9	87.0	83.8	86.6	79.8

decreases with an increase in growth time in almost a straight-line relationship (2- to 6-day malting period) is shown by the curves in Figure 1*a*, which are based on the average recovery of the four varieties corresponding to the malting temperature and moisture level concerned. Recovery decreases with an increase of temperature and growth time at both moisture levels. Recovery also was less at the high moisture. Recovery varied from 96.2% to 77.6%, depending

upon variety and malting conditions. Varieties responded somewhat differently to moisture, time, and temperature, the order of increasing recovery being as follows: Oderbrucker, Chevron, Peatland, and Wisconsin Barbless. Oderbrucker recovery was lowest at each moisture, at each time interval, and at each temperature. Differences between varieties were not as great at low moisture.

Steeping at 12°C. gave slightly less average recovery than at 16°C. Oderbrucker and Wisconsin Barbless reacted similarly to the two steep temperatures. Recovery for 16°C. steep temperature was greater than expected in most cases for 8 days at malting temperatures of 20° and 24°C. This may have unduly influenced the average for recovery at this steep temperature, thereby possibly invalidating the statement that recovery at 12°C. steep was less than that at 16°C.

TABLE V

THE INFLUENCE OF TEMPERATURE, MOISTURE, AND GROWTH TIME ON GROWTH INDEX OF FOUR BARLEY VARIETIES MALTED EXPERIMENTALLY

Steep temp., °C.	Malting temp., °C.	Variety of barley	Days of growth and moisture							
			2		4		6		8	
			Low	High	Low	High	Low	High	Low	High
16	12	Oderbrucker	49.5	48.3	50.3	56.3	56.0	92.0	68.0	95.5
		Wis. Barbless	49.8	49.8	53.3	68.8	71.5	96.3	77.0	105.8
		Peatland	49.3	50.3	52.8	58.3	75.3	93.0	73.5	99.0
		Chevron	49.3	49.3	53.0	69.0	73.3	83.0	71.5	98.3
	16	Oderbrucker	50.8	50.8	65.5	89.8	70.5	102.8	79.3	106.5
		Wis. Barbless	49.8	51.3	62.0	95.5	74.0	98.8	79.0	102.8
		Peatland	50.8	53.0	65.3	87.3	68.8	94.3	78.3	103.8
		Chevron	49.0	53.0	56.5	86.3	69.8	94.3	78.8	95.3
	20	Oderbrucker	49.3	69.3	58.3	81.8	69.8	90.3	68.0	96.8
		Wis. Barbless	49.5	60.5	62.5	91.3	68.0	98.0	76.5	109.0
		Peatland	49.3	65.0	67.3	88.0	72.0	87.3	74.3	97.0
		Chevron	46.3	61.5	60.5	84.8	71.3	86.5	74.5	102.8
	24	Oderbrucker	45.0	76.0	56.5	83.0	57.0	95.3	69.3	89.5
		Wis. Barbless	52.5	75.0	61.3	80.8	64.8	98.8	75.8	95.3
		Peatland	53.8	63.0	57.5	78.5	57.5	80.5	67.0	106.0
		Chevron	53.5	73.0	57.0	76.8	63.5	82.5	75.5	79.0
12	12	Oderbrucker	48.8	49.0	49.0	64.8	65.8	91.3	73.0	100.0
		Wis. Barbless	49.5	50.5	51.8	68.3	74.8	100.0	77.8	107.8
	16	Oderbrucker	49.8	49.8	59.3	93.0	82.3	98.0	77.3	106.3
		Wis. Barbless	49.3	49.8	66.0	91.5	73.0	97.3	86.8	112.3
	20	Oderbrucker	51.3	65.0	65.3	94.3	70.8	102.8	71.5	105.0
		Wis. Barbless	50.5	62.8	67.8	92.8	72.3	99.8	79.3	105.5
	24	Oderbrucker	50.3	81.0	68.0	91.3	57.8	89.8	79.5	96.5
		Wis. Barbless	51.8	69.3	65.0	100.8	77.0	90.5	75.0	90.0

Growth Index

Growth index values for the malts produced experimentally are recorded in Table V. Moisture exercised considerable influence, with the high moisture giving much more growth in all instances, the magnitude of the difference generally increasing with number of days. Average growth index showed a maximum at 16°C. After 8 days, however, the average of growth at 12°C. was nearly as much as at 16°C. or 20°C. and more than at 24°C. Growths for 12°C. and 16°C. malts at 2 days, at high moisture, were both low; by the end of the fourth day the average growth at 16°C. was greater than at 20°C. or 24°C. and by the end of the sixth day the 12°C. malts had grown as much as the 20°C. or 24°C. malts. The final growth index at 8 days

TABLE VI

THE INFLUENCE OF TEMPERATURE, MOISTURE, AND GROWTH TIME ON KERNEL WEIGHT OF MALT (MG.) OF FOUR BARLEY VARIETIES MALTED EXPERIMENTALLY

Steep temp., °C.	Malting temp., °C.	Variety of barley	Days of growth and moisture							
			2		4		6		8	
			Low	High	Low	High	Low	High	Low	High
16	12	Oderbrucker	27.1	26.6	27.2	26.0	25.8	25.6	25.6	24.8
		Wis. Barbless	25.3	25.7	24.5	24.5	23.5	23.7	23.5	23.0
		Peatland	24.6	23.8	23.8	23.9	24.0	23.3	22.2	22.2
		Chevron	24.0	24.1	23.4	22.9	23.0	21.5	22.5	23.9
	16	Oderbrucker	27.0	26.3	26.0	25.7	25.0	24.0	24.5	23.2
		Wis. Barbless	25.0	24.8	23.6	23.5	23.6	22.5	22.8	22.7
		Peatland	24.3	23.3	24.1	22.7	23.8	21.6	22.6	21.9
		Chevron	24.2	23.9	23.3	22.8	22.5	21.7	21.6	21.1
	20	Oderbrucker	26.2	25.2	25.5	24.6	24.3	23.3	25.0	22.9
		Wis. Barbless	24.0	23.4	23.8	22.9	22.9	21.1	23.0	22.7
		Peatland	24.4	23.3	23.1	22.7	22.4	21.0	22.7	21.6
		Chevron	23.7	23.2	22.7	21.9	21.9	21.3	22.2	20.1
	24	Oderbrucker	25.9	24.8	25.6	20.4	24.5	21.6	23.6	22.3
		Wis. Barbless	24.2	23.9	23.7	22.5	22.9	21.5	22.3	21.3
		Peatland	23.8	22.9	22.5	22.3	21.7	21.9	21.5	20.0
		Chevron	23.4	22.5	21.2	21.7	21.8	22.9	21.6	20.3
12	12	Oderbrucker	26.7	26.4	26.9	26.0	25.2	25.3	25.4	24.3
		Wis. Barbless	25.0	24.4	23.8	24.1	23.1	23.1	24.3	22.2
	16	Oderbrucker	27.2	26.6	25.7	25.2	25.9	24.1	24.5	26.7
		Wis. Barbless	24.6	25.1	24.4	23.4	22.9	22.8	23.4	22.0
	20	Oderbrucker	27.2	25.6	25.6	24.0	24.8	23.8	23.7	22.0
		Wis. Barbless	23.9	24.3	24.2	22.2	23.6	21.7	22.6	21.0
	24	Oderbrucker	25.6	24.4	24.2	23.1	24.8	22.6	23.0	21.1
		Wis. Barbless	24.2	23.5	22.9	21.7	22.0	21.7	22.6	20.4

at low moisture was less than 80 for all malting temperatures, indicating that the low moisture may have been a limiting factor. The varieties were not greatly different in growth indices when steeped at 16°C., but average indices at both steep temperatures show that Wisconsin Barbless produced more growth than Oderbrucker.

Kernel Weight

Kernel weight of malt, dry basis, followed the same general trends as recovery, which can be seen by comparing Tables IV and VI. High moisture reduced the kernel weight for the average of all varieties as did increase in growth time and temperature. At both moisture levels, kernel weight was reduced with increase in malting temperature. The varieties ranked in decreasing order for kernel weight of malt, as follows: Oderbrucker, Wisconsin Barbless, Peatland, and Chevron. Kernel weight of malt did not seem to be influenced greatly by steep temperatures although the same effect of moisture and temperature as indicated above was evident. Apparently the number of kernels used in determining kernel weight was not large enough or conditions were not controlled closely enough, since certain malting procedures gave weights that varied from the expected. For example the weights at 8 days for malts from 20° malting and 16° steep were higher than the weight for 6 days.

Extract

Moisture during malting proved to be important in influencing extract content, as shown in Table VII and Figure 1*b*. The extract values for 2-day malts at the lower temperatures are probably not reliable, since there was insufficient enzyme liberated to convert all of the starch in one hour. This is substantiated by the conversion times given in Table XI. Greatest variation in extract content occurred at the malting temperature of 12°C., where Wisconsin Barbless malted at high moisture for 2 days gave 59.7% and Oderbrucker malted at low moisture for 8 days gave 77.8%. Whether this figure is the highest obtainable is problematical, but it appears to be very near the maximum available in the barley. The average of high- and low-moisture 2-day malts showed an ascending extract with temperature in the order of 12°, 16°, 24°, and 20°C. The higher value for the 20°C. malts possibly indicates that 24°C. was too high for the best expression of extract in a 2-day malt. At 4 days, extract values for different moistures and temperatures converged within a 2% range and spread for later days to a maximum difference of about 5% at 8 days. After 8 days, using an average of the 2 moistures and all varieties, it will be seen that 12°C. gave distinctly the highest extract,

followed in order by 16°, 20°, and 24°C. Extract was gradually reduced after the 2-day period with increased malting times for 20° and 24°C. malts at the high moisture. Even with low moisture, extract was reduced increasingly after the 2 days' malting at 24°C. Maximum expression of extract was found for 16°, 20°, and 24°C.,

TABLE VII

THE INFLUENCE OF TEMPERATURE, MOISTURE, AND GROWTH TIME ON PERCENT OF MALT EXTRACT OF FOUR BARLEY VARIETIES MALTED EXPERIMENTALLY

Steep temp., °C.	Malting temp., °C.	Variety of barley	Days of growth and moisture							
			2		4		6		8	
			Low	High	Low	High	Low	High	Low	High
16	12	Oderbrucker	67.2	64.9	75.1	73.1	77.0	75.3	77.8	76.2
		Wis. Barbless	67.3	59.7	71.1	70.0	72.2	71.4	72.5	72.3
		Peatland	67.6	67.2	74.0	73.6	74.9	74.0	76.6	74.8
		Chevron	68.5	66.9	72.8	72.9	73.8	73.5	74.8	73.7
	16	Oderbrucker	72.5	71.5	75.8	75.9	75.4	75.7	76.1	74.6
		Wis. Barbless	69.6	69.6	71.5	71.6	70.8	71.4	71.1	69.9
		Peatland	69.4	71.8	74.0	74.8	74.2	74.5	74.3	73.5
		Chevron	71.4	71.6	72.9	72.8	73.1	72.8	72.5	72.5
	20	Oderbrucker	75.1	75.2	76.2	75.3	76.5	75.1	75.8	74.2
		Wis. Barbless	71.7	71.3	71.3	71.6	71.6	71.2	71.0	70.0
		Peatland	73.6	74.6	74.0	73.5	74.6	73.5	73.0	72.6
		Chevron	73.1	74.1	73.5	72.7	73.2	72.2	72.5	71.8
	24	Oderbrucker	75.6	76.0	74.1	74.5	74.0	72.0	72.8	71.9
		Wis. Barbless	70.2	71.7	70.6	71.0	70.5	71.1	70.7	70.4
		Peatland	72.7	74.0	73.4	72.3	73.3	72.8	72.8	72.7
		Chevron	71.3	73.1	71.3	72.0	72.4	71.3	72.0	70.5
12	12	Oderbrucker	66.0	67.9	74.8	74.9	77.0	76.1	77.7	77.1
		Wis. Barbless	66.4	61.7	71.2	70.9	72.0	71.8	72.2	72.5
	16	Oderbrucker	72.3	71.6	76.1	75.6	76.4	75.1	77.7	75.0
		Wis. Barbless	69.6	68.5	71.8	71.6	70.7	70.7	70.5	70.4
	20	Oderbrucker	75.5	75.9	75.9	75.1	77.0	75.6	76.5	75.0
		Wis. Barbless	71.2	71.0	70.9	71.3	71.1	71.2	71.9	71.3
	24	Oderbrucker	76.2	76.9	76.7	74.7	73.2	73.1	71.8	70.8
		Wis. Barbless	71.1	72.1	71.7	71.7	70.3	69.8	69.9	69.7

but not definitely for 12°C. The varietal order for extract from high to low was Oderbrucker, Peatland, Chevron, and Wisconsin Barbless and the differences were significant. No great difference in varietal response was encountered for moistures, times of malting, or temperatures of malting. Extract of Oderbrucker decreased more than that of Wisconsin Barbless for longer growth times at 24°C. This is probably not a varietal difference, since Oderbrucker was attacked by

molds. At 16°C., low moisture gave less extract at 2 days than the high moisture, but this might have been caused by a greater production of diastatic enzymes at the higher moisture. Average extract content for Oderbrucker was about the same for the 12° and 16°C. steep temperatures. The same can be said of Wisconsin Barbless.

Diastatic Power

The range in diastatic power varied from 52° to 260° Lintner, according to variety and treatment. (See Table VIII and Figure 1*c*.) At the outset it may be said that Oderbrucker did not respond as well to malting conditions as expected. This belief is supported by some unpublished experimental malting studies. Moisture, temperature of

TABLE VIII

THE INFLUENCE OF TEMPERATURE, MOISTURE, AND GROWTH TIME ON DIASTASE (°L.) OF FOUR BARLEY VARIETIES MALTED EXPERIMENTALLY

Steep temp., °C.	Malting temp., °C.	Variety of barley	Days of growth and moisture							
			2		4		6		8	
			Low	High	Low	High	Low	High	Low	High
16	12	Oderbrucker	62	67	95	99	107	132	150	156
		Wis. Barbless	65	60	101	116	124	134	143	167
		Peatland	52	88	111	132	160	185	154	177
		Chevron	83	57	163	189	206	258	231	260
	16	Oderbrucker	73	76	97	96	117	115	111	128
		Wis. Barbless	78	95	121	109	141	131	121	164
		Peatland	72	96	106	136	138	192	144	197
		Chevron	116	128	195	167	203	242	198	257
	20	Oderbrucker	77	97	114	123	124	146	89	133
		Wis. Barbless	78	97	109	137	96	153	126	167
		Peatland	95	122	105	128	126	172	121	140
		Chevron	135	162	149	223	176	219	176	189
	24	Oderbrucker	73	100	105	124	88	121	93	115
		Wis. Barbless	80	110	80	143	98	126	106	140
		Peatland	74	131	70	144	85	153	87	145
		Chevron	104	154	78	161	120	168	132	202
12	12	Oderbrucker	63	71	98	104	115	121	146	136
		Wis. Barbless	66	60	106	111	126	136	155	169
	16	Oderbrucker	79	89	114	122	130	129	121	155
		Wis. Barbless	89	79	119	135	117	147	110	161
	20	Oderbrucker	96	126	95	145	121	118	98	133
		Wis. Barbless	94	119	124	133	105	138	103	145
	24	Oderbrucker	98	110	103	124	105	119	83	121
		Wis. Barbless	107	132	107	143	93	147	98	145

malting, and length of growing time had highly important influences on diastase. Under the given conditions there seemed to be a close relationship between the factors that influenced acrospire growth and the development of diastatic power. High moisture favored the development of diastase. Diastase generally increased with malting-time increase, with marked exceptions after the 6-day period. Using the averages of all malting temperatures, diastatic power increased at each moisture until the sixth day, when a break occurred. At high moisture the increase in diastatic power from 6 to 8 days was slight, while at the low moisture there was no increase with an increase in time. The increase of diastatic power with time at high moisture was rather rapid at 12° and 16°C. through 8 days. At 24°C. diastase gradually increased to 8 days, but at 20°C. it declined after 6 days. At 2 days' growth, diastase was increased with increase in temperature, but as time increased the low-temperature malts increased in diastase faster than high-temperature malts. The varieties ranked on the basis of diastatic power from high to low in the following order: Chevron, Peatland, Wisconsin Barbless, and Oderbrucker. The highest diastatic powers for the varieties were 260, 197, 167, and 156, in the order named. As suggested earlier, Oderbrucker was distinctly off type from its usual reaction. Peatland averaged 40°L. more diastase at high moisture than at low moisture, while Oderbrucker had only 16°L. more, which is evidence of unequal varietal response to moisture increase. High temperatures depressed the diastatic power of Chevron and Peatland relatively more than of Oderbrucker or Wisconsin Barbless. Using both moistures and all temperatures, Chevron increased 88°L. between 2 and 8 days of malting, while Peatland and Wisconsin Barbless increased 54° and 59°L., respectively, during that period. This suggests that the rate of enzymatic activation is different for Peatland and Chevron. Steeping and malting temperatures used in this experiment did not seem to have clear-cut influences on the lots of Oderbrucker or Wisconsin Barbless barley. In Oderbrucker and Wisconsin Barbless, as was true with the other two varieties, 12° and 16°C. malting temperatures developed less diastase in the early malting periods than the higher temperatures 20° and 24°C., but the reverse was true at the end of the malting period.

The 12°C. steep gave higher diastatic values for early growth periods than 16°C. steep, but this influence did not continue throughout the 8 days' growth period.

Malt Nitrogen

The influence of growth time and malting temperature on malt nitrogen was not so clear-cut as on other factors studied. Moisture seemed to have little effect except at 8 days' growth, where high mois-

ture gave higher nitrogen on a percentage basis. (See Table IX.) At this same time respiration loss was greatest with recovery being least, and therefore malt nitrogen made up a higher percentage of the total dry matter than in the earlier stage of malting. One may speculate that, during growth, carbohydrates and nitrogen compounds had both

TABLE IX

THE INFLUENCE OF TEMPERATURE, MOISTURE, AND GROWTH TIME ON PERCENT OF MALT NITROGEN OF FOUR BARLEY VARIETIES MALTED EXPERIMENTALLY

Steep temp., °C.	Malting temp., °C.	Variety of barley	Days of growth and moisture							
			2		4		6		8	
			Low	High	Low	High	Low	High	Low	High
16	12	Oderbrucker	1.96	2.18	2.06	2.04	1.97	2.05	1.98	2.07
		Wis. Barbless	2.19	2.30	2.11	2.11	2.05	2.08	2.13	2.10
		Peatland	2.27	2.48	2.27	2.37	2.24	2.27	2.22	2.37
		Chevron	2.50	2.24	2.50	2.60	2.50	2.35	2.47	2.54
	16	Oderbrucker	2.23	2.06	2.04	2.03	2.04	1.96	2.04	2.23
		Wis. Barbless	2.27	2.23	2.07	2.11	2.12	2.10	2.13	2.26
		Peatland	2.39	2.35	2.49	2.34	2.30	2.46	2.30	2.50
		Chevron	2.59	2.54	2.60	2.54	2.54	2.45	2.55	2.56
	20	Oderbrucker	2.00	2.00	2.07	2.10	2.06	2.07	2.12	2.13
		Wis. Barbless	2.12	2.12	2.14	2.05	2.08	2.05	2.21	2.15
		Peatland	2.34	2.26	2.34	2.31	2.32	2.34	2.37	2.41
		Chevron	2.53	2.47	2.52	2.49	2.54	2.55	2.54	2.61
	24	Oderbrucker	2.05	2.05	2.07	2.02	2.14	2.14	2.11	2.17
		Wis. Barbless	2.09	2.18	2.07	2.08	2.10	2.18	2.16	2.23
		Peatland	2.34	2.37	2.28	2.34	2.37	2.39	2.32	2.40
		Chevron	2.56	2.42	2.58	2.66	2.54	2.54	2.66	2.65
12	12	Oderbrucker	2.14	2.08	1.98	1.98	1.98	2.03	2.03	2.02
		Wis. Barbless	2.21	2.13	2.01	2.05	2.02	2.07	2.07	2.09
	16	Oderbrucker	2.06	2.04	2.09	2.05	2.13	2.05	2.08	2.16
		Wis. Barbless	2.23	2.16	2.13	2.16	2.13	2.13	2.19	2.18
	20	Oderbrucker	2.02	2.01	1.98	2.02	2.12	2.07	2.09	2.12
		Wis. Barbless	2.14	2.08	2.13	2.07	2.10	2.14	2.13	2.11
	24	Oderbrucker	2.05	2.08	2.06	2.09	2.11	2.13	2.13	2.17
		Wis. Barbless	2.11	2.05	2.10	2.10	2.18	2.05	2.16	2.18

been respired, but the proportion of carbohydrates combusted was much greater than of nitrogen. The nitrogen translocated to rootlets removed before analysis should also be kept in mind in discussing the nitrogen metabolism (degradation). The nitrogen trend on a percentage of dry matter was downward for the first 6 days and then moved upward on the eighth day. At 4 days the nitrogen percentage at each

malting temperature was about the same, whereas at 8 days the values lined up in the following descending order: 24°, 20°, and 16°, all of which are about equal, and 12°C. the lowest. For low moisture at 8 days there was some tendency for the malt nitrogen to increase with temperature increase. Nitrogen in Wisconsin Barbless was consistently less at 4 and 6 days than at 2 and 8 days; Chevron and Oderbrucker increased in most cases from 6 to 8 days, while Peatland did not change greatly throughout the growing period. Chevron had slightly more nitrogen at the lower moisture, while the other varieties in most cases had more at the higher moisture. The varietal rank concerning malt nitrogen was the same as that for diastatic power and root loss, with Chevron being first. Steep temperature apparently had little effect on the malt nitrogen of Oderbrucker and Wisconsin Barbless.

TABLE X

THE INFLUENCE OF TEMPERATURE, MOISTURE, AND GROWTH TIME ON WORT NITROGEN IN RELATION TO MALT NITROGEN OF FOUR BARLEY VARIETIES MALTED EXPERIMENTALLY

Steep temp., °C.	Malting temp., °C.	Variety of barley	Days of growth and moisture							
			2		4		6		8	
			Low	High	Low	High	Low	High	Low	High
16	12	Oderbrucker	18.3	15.6	29.1	26.2	34.2	31.5	37.9	39.1
		Wis. Barbless	17.5	15.2	24.5	24.2	25.5	28.2	26.7	31.4
		Peatland	20.6	19.0	26.2	26.4	31.5	31.9	34.1	34.9
		Chevron	21.1	20.0	29.4	28.4	31.6	37.3	33.7	37.0
	16	Oderbrucker	23.4	23.5	32.7	35.4	34.6	41.1	37.6	38.4
		Wis. Barbless	19.8	19.9	26.1	27.9	25.1	29.2	26.6	29.5
		Peatland	23.6	24.6	27.2	32.8	30.5	32.9	31.7	33.6
		Chevron	24.4	26.6	27.9	32.3	28.4	35.2	30.0	35.5
	20	Oderbrucker	26.7	30.2	31.4	34.2	33.5	38.7	35.4	39.3
		Wis. Barbless	23.6	26.3	23.9	27.5	24.3	28.5	23.3	26.3
		Peatland	26.7	33.0	26.9	31.0	28.2	32.5	27.2	32.2
		Chevron	26.5	32.9	27.3	30.9	26.7	31.3	27.1	30.9
	24	Oderbrucker	29.3	33.7	41.8	40.7	28.9	38.6	32.1	37.0
		Wis. Barbless	24.0	27.4	24.5	28.4	24.3	30.2	25.4	28.2
		Peatland	26.8	30.9	26.9	30.4	28.0	32.5	30.7	39.9
		Chevron	24.3	31.0	25.2	30.0	27.7	32.0	27.5	30.7
12	12	Oderbrucker	17.3	18.3	28.4	29.5	35.1	35.7	37.4	42.8
		Wis. Barbless	17.7	17.3	26.6	25.9	28.6	29.9	28.6	32.5
	16	Oderbrucker	24.2	22.6	31.0	35.6	32.6	38.7	37.4	40.6
		Wis. Barbless	19.4	27.7	25.7	27.5	25.8	28.7	25.0	30.0
	20	Oderbrucker	28.2	30.7	33.7	41.1	34.4	39.6	36.5	45.8
		Wis. Barbless	23.3	26.9	25.6	30.0	24.7	33.8	25.0	28.9
	24	Oderbrucker	28.6	33.5	34.9	41.3	28.6	38.5	33.1	38.1
		Wis. Barbless	23.7	28.7	25.0	28.3	24.0	29.3	24.9	31.1

Wort Nitrogen as Percentage of Malt Nitrogen

The percentage of wort nitrogen in relation to malt nitrogen ranged from more than 45% to about 15% according to variety and method of malting. The data are given in Table X and curves in Figure 1*d*, where it will be seen that the trends closely parallel those for diastatic power. For the most part the influence of malting environment was pronounced. With moisture alone considered and temperatures averaged, the higher moisture gave a higher percentage of wort nitrogen at all growth periods and it increased with longer malting time for either moisture. Malting temperature also influenced soluble nitrogen percentage, especially when time of growth was considered, because the high temperatures favored more soluble nitrogen in early growth phases while the lower temperatures were more favorable at the longer growth time. At 6 and 8 days' growth, wort nitrogen percentage was greater at the lower temperatures. There was less difference between the wort nitrogen percentages of 6- and 8-day malts than of 2- and 4-day malts. There was a similarity between wort nitrogen trends at both moisture levels as growth time increased. Using averages of all malt times and both moistures, the wort nitrogen of Chevron malts decreased with temperature rise, which is in contrast to the other three varieties. All varieties showed an increased wort nitrogen percentage with increase in growing time, but the increase of Chevron and Wisconsin Barbless between 6 and 8 days was smaller than for the other two varieties. The varietal rank from high to low for percentage wort nitrogen was Oderbrucker, Peatland, Chevron, and Wisconsin Barbless, with the second and third varieties not being significantly different. Steep temperature seemed to influence soluble nitrogen, since malts from the 12°C. steep gave higher percentages than did those from the 16°C. steep.

Conversion Time

Conversion time given in Table XI varied from more than an hour to less than 5 minutes, according to malting treatment and variety. For the most part conversion time decreased as malting time increased. The effect of malting temperature on conversion time was much more important during the earlier growth period than later. The conversion time for 12°C. and 16°C. malting temperature was much greater at 2 days than 20° or 24°C., while at 8 days the 12° and 16°C. malt temperatures averaged about the same conversion as 20° and 24°C. The high-moisture malts grown at 12°C. for 4 days were slower in conversion time than the low-moisture malts. Otherwise low-moisture malts required more time for conversion on the average than did high-moisture malts. Conversion time at high moisture content

decreased in general with malting time increase, but at low moisture it increased at 8 days over that for 6 or 4 days. The varietal rank from low to high for conversion time was Chevron, Oderbrucker, Wisconsin Barbless, and Peatland, with no significant difference between the middle pair. This arrangement is considerably different from the

TABLE XI

THE INFLUENCE OF TEMPERATURE, MOISTURE, AND GROWTH TIME ON CONVERSION TIME IN MINUTES OF FOUR BARLEY VARIETIES MALTED EXPERIMENTALLY

Steep temp., °C.	Malting temp., °C.	Variety of barley	Days of growth and moisture							
			2		4		6		8	
			Low	High	Low	High	Low	High	Low	High
16	12	Oderbrucker	>60	>60	15	35	10–15	10	25–30	7–10
		Wis. Barbless	>60	>60	20	30	10–15	10–15	10	5–7
		Peatland	>60	>60	15	25	10	10–15	10–15	10
		Chevron	>60	>60	7	10	7	7	7–10	7
	16	Oderbrucker	60	>60	7	5	5–7	7	5–7	<5
		Wis. Barbless	35	30–35	15	10	15	10	15–20	10
		Peatland	45	30–35	15	10	15	10	15–20	10
		Chevron	30	20	7	7–10	10	5	7	7
	20	Oderbrucker	20	10–15	7	7–10	5	<5	10	5–7
		Wis. Barbless	20–25	10–15	15	10–15	20	10–15	20	5–7
		Peatland	30	10–15	10–15	10	30	7–10	20	15
		Chevron	20	10	10	7–10	15	7–10	15	10
	24	Oderbrucker	10–15	10–15	10–15	15–20	15	5–7	7	<5
		Wis. Barbless	20	10–15	25	10–15	20	10–15	10	10–15
		Peatland	50	15–20	35	15–20	25	10–15	20	10–15
		Chevron	15	15–20	15	15	15	<5	10	5
12	12	Oderbrucker	>60	>60	20	20	7	6	<5	5–7
		Wis. Barbless	>60	>60	20	15	10	7–10	10–15	10
	16	Oderbrucker	>60	>60	10	15	5	<5	7	5–7
		Wis. Barbless	>60	>60	20	15	15–20	5–7	10	10
	20	Oderbrucker	10–15	15	7–10	5	5	<5	10	5
		Wis. Barbless	15	10–15	15	10	15	7	15–20	10–15
	24	Oderbrucker	10	7	10	5–7	10–15	<5	7	<5
		Wis. Barbless	20	10	15	7	20–25	7–10	10	7–10

varietal rank when considering nitrogen in the wort, or diastase. It is interesting to note that Wisconsin Barbless required more than 5 minutes for all of the methods of malting. Peatland grown at low moisture required more time for conversion than did other varieties. Chevron malt grown at 16°C. converted most rapidly, while the malts from the other varieties were more rapid at the 20°C. malting temperature. At high moisture Oderbrucker and Wisconsin Barbless required

the least time for conversion at 8 days, while Chevron and Peatland required the least time at 6 days. Conversion time of Oderbrucker and Wisconsin Barbless malts was a little less for malts steeped at 12°C. than for those steeped at 16°C.

TABLE XII

THE INFLUENCE OF TEMPERATURE, MOISTURE, AND GROWTH TIME ON WORT COLOR (LOV. 52) OF FOUR BARLEY VARIETIES MALTED EXPERIMENTALLY

Steep temp., °C.	Malting temp., °C.	Variety of barley	Days of growth and moisture							
			2		4		6		8	
			Low	High	Low	High	Low	High	Low	High
16	12	Oderbrucker	1.4	1.3	1.6	1.4	1.4	1.4	1.5	1.5
		Wis. Barbless	1.4	1.0	1.5	1.3	1.5	1.3	1.4	1.4
		Peatland	1.1	1.1	1.4	1.4	1.5	1.4	1.5	1.4
		Chevron	1.2	1.3	1.5	1.4	1.8	1.5	1.5	1.6
	16	Oderbrucker	1.4	1.4	1.4	1.4	1.5	1.6	1.6	1.8
		Wis. Barbless	1.4	1.4	1.5	1.4	1.5	1.5	1.4	1.4
		Peatland	1.4	1.4	1.5	1.6	1.5	1.4	1.4	1.5
		Chevron	1.4	1.3	1.5	1.5	1.5	1.4	1.5	1.5
	20	Oderbrucker	1.6	1.4	1.4	1.6	1.5	1.8	2.0	1.6
		Wis. Barbless	1.5	1.4	1.5	1.5	1.5	1.6	2.0	1.5
		Peatland	1.4	1.8	1.6	1.7	1.5	1.6	1.5	1.6
		Chevron	1.4	1.4	1.6	1.4	1.5	1.6	1.5	1.6
	24	Oderbrucker	1.8	1.4	1.4	1.9	1.5	1.2	1.9	2.1
		Wis. Barbless	1.9	1.5	1.6	1.8	1.9	1.9	2.0	2.8
		Peatland	1.8	1.6	1.8	2.0		2.0	2.3	2.3
		Chevron	1.8	1.5	1.9	1.9	1.8	1.9	1.9	1.6
12	12	Oderbrucker	1.1	1.2	1.5	1.4	1.3	1.3	1.4	1.5
		Wis. Barbless	1.1	1.0	1.4	1.4	1.3	1.3	1.3	1.4
	16	Oderbrucker	1.4	1.4	1.3	1.4	1.4	1.5	1.6	1.8
		Wis. Barbless	1.1	1.1	1.4	1.3	1.4	1.4	1.4	1.4
	20	Oderbrucker	1.3	1.3	1.5	1.6	1.3	1.4	1.4	1.5
		Wis. Barbless	1.4	1.3	1.5	1.4	1.6	1.4	1.4	1.4
	24	Oderbrucker	1.4	1.5	1.5	1.6	1.5	1.9	2.5	2.5
		Wis. Barbless	1.5	1.3	1.5	1.4	1.6	1.4	1.9	2.0

Color

Color of wort in Lovibond units (Series 52) varied from 1.0 to 2.8 as recorded in Table XII. Color increased with the longer growth period and also with higher malting temperatures. Oderbrucker malts did not increase in color at the 24° malting temperature as much as the other varieties. Moisture of malting as well as variety had little influence on color. In the portion of the experiment using

Oderbrucker and Wisconsin Barbless at 12° and 16°C. steeps, malting temperature again was important, the higher temperatures giving higher color reactions, and also color increased with longer growth period. Lower steep temperatures gave less color. There was an increase in color between 2 and 4 days' growth, but increases in color were greatest at 8 days with higher temperatures. Oderbrucker and Wisconsin Barbless had the same color reading at the 16° steep but the color of the latter was less in the 12°C. steep. As an average for both steep temperatures, the two varieties had nearly the same color for 4 and 6 days' growth, but Wisconsin Barbless had slightly less color than Oderbrucker at 2 and 8 days' growth. Wisconsin Barbless averaged less color at high moisture than Oderbrucker, when both steep temperatures are considered.

Analysis of Variance

The data in Tables II to XII, inclusive, have been subjected to the analysis of variance, recognizing, however, limitations in the validity of the procedure for interpretation of the results. In Table XIII

TABLE XIII

SUMMARY OF *F* VALUES FROM ANALYSIS OF VARIANCE COMPARED TO 1% AND 5% LEVELS OF SIGNIFICANCE OF FOUR BARLEY VARIETIES MALTED EXPERIMENTALLY AT 16°C. STEEP TEMPERATURE

	DF	Respiration and steep loss	Root loss	Recovery	Growth index	Kernel wt. of malt	Extract of malt	Diastatic power of malt	Malt nitrogen	Wort N in relation malt N	Conversion time	Wort color
Varieties (V)	3	1[1]	1	1	—	1	1	1	1	1	1	—
Moisture (M)	1	1	1	1	1	1	1	1	—	1	1	—
Days Growth (D)	3	1	1	1	1	1	1	1	1	1	1	1
Malt Temperature (MT)	3	1	1	1	1	1	1	1	1	1	1	1
V×M	3	5[2]	1	1	—	5	—	1	5	—	1	—
V×D	9	5	—	5	—	—	—	1	1	1	5	—
V×MT	9	1	5	5	—	—	—	1	—	1	1	5
M×D	3	1	1	1	1	—	—	5	5	5	5	—
M×MT	3	1	1	1	—	5	1	1	—	1	1	—
D×MT	3	1	1	1	1	—	1	1	1	1	1	—
V×M×D	9	—	—	—	—	—	—	—	—	—	—	—
V×D×MT	27	—	—	—	—	—	5	1	1	1	1	—
M×D×MT	9	—	—	—	5	—	—	5	—	—	—	—
V×M×MT	9	—	5	—	—	—	—	—	—	—	—	—
V×M×D×MT	27											

[1] 1 = excess of 1% level of significance.
[2] 5 = excess of 5% level of significance.

is given a summary of the *F* values obtained in the section of the study using the 4 varieties, 2 moistures, 4 growth periods, and 4 malt temperatures. The figure "1" denotes that the *F* value exceeds the requirement of the 1% point, and "5" indicates that the *F* value obtained was in excess of the amount required for the 5% level of significance. Where "–" occurs the *F* value was insignificant. Part of the foregoing

discussion has been based on this summary. Nevertheless a brief review of the analysis might be of benefit at this point.

Varieties proved different for all malting factors studied except for growth index and color of wort. This does not mean that all varieties were different from each of the remaining three, but that at least one variety was different from one or more of the others. High and low malting moistures had different effects on all factors observed except for malt nitrogen and wort color. Growth time (2, 4, 6, and 8 days) and malting temperature influenced sharply all malting factors studied in this investigation. Varieties and moistures in this study did not interact for extract, wort nitrogen, growth index, and color of wort, but responded differentially to other factors mentioned in this study. Varieties and malting temperatures interacted similarly to varieties and days' growth except for root loss, malt nitrogen, and wort color. These first-order interactions were significant for growth index, kernel weight, and extract. Moisture and growth time influenced differently all factors tested except extract, kernel weight, and wort color. Differential reactions were recorded for moisture and malt temperatures for all malting measurements except malt nitrogen, growth index, and color of wort. And finally, as might be expected, growth time and malting temperature influenced all malting factors differentially except for kernel weight and color of wort. To review the analysis of variance, some of the interactions that proved statistically significant may be indicative of natural trends that have been produced by a series of temperatures or growth periods, and in this light the trends are what might be expected instead of random or disorderly responses. Where insignificant interactions occur as in the case of extract, there is evidence that an optimum has been reached with lower points on either side. In this analysis the third-order interaction of varieties × moisture × growth periods × malting temperatures, making up 27 degrees of freedom, was used as error.

In the portion of the experiment concerning the two steep temperatures, the results have been interpreted cautiously, because the Oderbrucker barley did not react as anticipated in the light of other experimental malting. Only the action of steep temperature and the interactions will be discussed. Steep temperature (12° and 16°C.) affected recovery, growth, wort nitrogen, and wort color. Varieties and steep temperature interacted only for wort color. Moisture and steep temperature reacted differentially for wort nitrogen and color. Time of growth and steep temperature influenced root loss, recovery, growth, and wort color unequally. And finally moisture and steep temperature interacted for root loss, recovery, and conversion time. Even though the differences attributable to steep temperatures are not

great it is believed on the basis of unpublished work that a wider range in steep temperatures would prove to have more influence on the quality of the finished malt.

Discussion and Summary

Recovery of malt (the proportion of cleaned malt to the amount of barley) is influenced markedly by moisture, malting temperature, and growth time. Since recovery is determined largely by root loss, and also by respiration and steep loss, these three factors bear a close relationship. Recovery for practical purposes may be considered as the complement of the combination of the three losses just named. Likewise a comparison of the kernel weight of malt with the kernel weight of barley should measure recovery rather accurately. Since these measurements are closely associated, there is a general similarity of their curves and trends as produced by different malting conditions. A similarity, though not to such an extent, exists between growth index, diastase, and wort nitrogen. What influences one seems likely to influence the other.

It should be emphasized here that this association of malt factors holds only for the given set of conditions studied and perhaps should not be interpreted too broadly. Extract, malt nitrogen, color, and conversion time seem to be independent in their responses to the different malting conditions used. From the foregoing data the writers would like to point out that factors concerned with malting quality are greatly influenced by conditions that may be controlled under malt house operation. It is granted that some of the methods used experimentally are not practicable for a commercial malt house, but this type of experimentation is necessary in order to learn trends and effects. These responses are greater than those described in a recent paper by Sallans and Anderson (1939), probably because a wider range of conditions was used.

Finally, it should be pointed out that this study indicates that no simple method has been found that will produce maxima for all quality and efficiency factors. For example high extract may be obtained by using a low moisture, low temperature, and long malting time. This, however, does not produce the greatest wort nitrogen, diastase or shortest conversion time. On the contrary, high diastase may be produced by malting at high moisture for a longer period at a low temperature, but this does not give the greatest extract. Or, if only a short period of time is allowed for malting, temperature and moisture increases would serve to advance malting. The problem resolves itself largely into what type of malt is wanted, and then, with a knowledge of the effects of different malting environments, a method

for obtaining the desired type may be outlined. Greater recovery may be had by using low temperature and low moisture for a shorter period of malting time, but this is not likely to give good modification as measured by the amount of wort nitrogen. More wort nitrogen may be produced with almost the same procedure that produces higher diastase, namely, high moisture and low temperature for 6 days or longer. If the production of a moderately good malt in five days is desired, the following conditions could be considered: malting temperature of about 16°C. (steep temperature of 12°–16°C.) and intermediate moisture of about 46%. If less time for malting is desired, a moisture increase could be suggested or a small increase in malting temperature probably would compensate in part for reduced time. If time is not a factor in plant operation, low moisture (43%–44%) and low malting temperature (12°C.) would give high extract, diastase, and wort nitrogen for 8 days' growth and at the same time give a high recovery.

Earlier in this paper reference was made to the possibility of changing malting conditions systematically or periodically. It seems likely that malting methods prescribed after such a series of experiments would more likely approach maximum quality of malt and full plant efficiency than constant conditions as studied in these investigations. Nevertheless to approach the question of malting methods from the standpoint of constant conditions provides a basis both for interpretation of environmental influences and for planning additional experiments for study of certain fluctuating conditions.

Acknowledgment

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A STUDY OF SOME DIFFERENCES IN GLUTEN PROPERTIES EXISTING BETWEEN VARIETIES AND TYPES OF WHEAT

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Quality evaluation of wheat varieties is a difficult problem for the cereal chemist. Among the various factors which are included in the term "quality" the biochemical properties of the gluten rank high in importance. It is the combined effect of these properties that are registered in the behavior of the dough during fermentation, as well as in the quality of the finished loaf. While the properties of the baked loaf produced through the use of a suitable baking formula are still considered to be a final measure of flour quality, the employment of various forms of dough-testing devices that attempt to evaluate some physical property or properties of the dough or gluten is becoming more general. Dough-mixing studies appear to be among the more promising of these physical methods, and marked differences in the characteristics of mixer curves obtained from different varieties of bread wheats have been found. These curves, however, do not yield pertinent information in regard to the more fundamental properties of the wheat gluten protein, but tend to measure the effects of many variables.

The viscosity of flour-water suspensions in relation to wheat quality has been investigated by a number of workers. Gortner and Doherty (1918), Sharp and Gortner (1923), Lüers and Ostwald (1919, 1920a, 1920b), Hendel and Bailey (1924) and other workers have studied this phase of the problem and reference is made to their published works for further information in connection with viscosity studies in relation to baking strength.

Gortner, Hoffman, and Sinclair (1929), Gortner (1927), Geddes and Goulden (1930), Harris (1931), and Mangels (1934) have studied the relationships involved in wheat-protein peptization and wheat-quality evaluation. The final conclusion to be derived from these studies is that crude protein content is as indicative of baking strength as any information likely to be obtained from protein-peptization studies.

Changes in rotatory power of protein solutions prepared from wheats of different quality by the method of Osborne were examined by Woodman (1922) and Blish and Pinckney (1924). The results obtained by these workers were in agreement as to the identity of the

gliadins isolated from different wheats but did not agree respecting the glutenin fraction. Kent-Jones (1926) investigated glutenin by this racemization method. Little difference was found in the specific rotations of glutenins prepared from English and Manitoba wheats except in the case of wheats of extreme divergence in baking strength. This worker postulated that any chemical differences which do exist do not suffice to explain variations in baking strength.

Blish and Sandstedt (1933) separated what appeared to be three distinct proteins from wheat gluten. Harris and Bailey (1937) repeated their procedure on a number of glutens prepared from flours of marked differences in baking strength. Statistical analysis of the resultant data showed a significant correlation between gliadin content and loaf volume.

The method of dispersing wheat gluten in sodium salicylate solution rather than the usual solvents, acid and alkali, was advocated by Rose and Cook (1935). Harris (1937, 1938, 1938a) and Harris and Johnson (1939, 1940) employed gluten dispersions in measuring the effects of proteolytic enzymes and flour oxidizers upon wheat gluten properties. Various types and classes of wheat were also examined with respect to possible differences in the biochemical properties of the gluten dispersions, and such attributes as protein dispersibility, quantity of protein thrown down from the dispersions by $MgSO_4$, viscosity, etc were determined. Marked differences in these properties were obtained by varying the enzyme treatment. Significant changes were found in these properties among wheat varieties.

The present investigation was undertaken with the purpose of confirming the results obtained from previous work by studying a larger number and range of samples from another crop year. A rotary shaker had been constructed which rendered it possible to obtain more uniform shaking of the flasks while dispersion was proceeding, than had been achieved in the instance of the work already reported. This shaker was described by Harris and Johnson (1940a), and used by them in work of this nature. It was also deemed advisable to determine the "resistance values" of the glutens prepared from these wheats and to ascertain whether significant differences in this property existed between the various wheats included in this study.

Experimental Material and Methods

Fifteen samples of wheat were collected from different wheat-growing regions of the continental United States. These samples comprised representatives of varieties of the hard red spring, durum, hard red winter, soft red winter, and white wheat classes. The states represented were North Dakota, Kansas, Nebraska, Indiana, and

Washington. The wheats were cleaned, graded, and milled into straight-grade flour on an Allis-Chalmers experimental mill. The humidity of the mill room was controlled at approximately 60% during the milling process. The resultant flours were baked by the malt-phosphate-bromate method with 5% of sucrose, instead of 2.5% as originally required by the standard basic formula. Protein, ash, and moisture determinations were run on the flours.

These flours were also mixed into doughs, using the standard basic formula with 5% sucrose. The doughs were prepared with the Hobart-Swanson mixer, three-minute mixing times being used. Immediately following mixing, the gluten was washed from the dough under a small standardized stream of 0.1% sodium phosphate solution of pH 6.8 by the method of Dill and Alsberg (1924). The glutens were allowed to stand for 15 to 30 minutes under the phosphate solution, and were then divided into the required quantities and dispersed in 10% sodium salicylate solution by constant agitation in the electric rotary shaker for several days. The speed of this machine is adjusted so as to obviate any possibility of foaming the dispersions, with consequent danger of surface denaturation of the protein. A number of gluten concentrations were used to obtain data suitable for representing the relationship between viscosity and concentration. When the dispersion process appeared to be complete the dispersions were centrifuged to remove undispersed protein and starch material and the protein content ascertained by the Kjeldahl-Gunning procedure. Viscosity was determined by means of an Ostwald capillary pipette at a temperature of 25°C. The quantity of gluten protein thrown down by the addition of 6% by volume of concentrated $MgSO_4$ solution to the dispersions also was found, by a method described by the authors in previous publications.

"Resistance" tests were run on a 15-g. portion of the crude gluten by means of the "tenderness tester" described by Binnington, Johannson, and Geddes (1939) and used by Harris and Johnson (1940a) in evaluating differences in resistance between glutens treated with varying quantities of proteolytic enzymes. Reference is made to these papers for the methods involved in obtaining the resistance values.

A further series of determinations was made to find the relative rates at which the glutens prepared from these wheats as described would disperse in sodium salicylate under constant shaking. The rate of dispersion was measured by increase in viscosity as found by the Ostwald pipette.

Discussion of Results

In Table I are presented the origin and description of the wheats used in this investigation, with comparative milling and baking data

obtained from them. The wheats are grouped according to class and are arranged within the group by increasing crude protein content. These wheats were grown during the 1939 crop season and were sound and free from damage of any nature. Explanations of loaf appearance are included in the table to facilitate an understanding of the results obtained.

TABLE I

COMPARATIVE MILLING AND BAKING DATA ON A NUMBER OF WHEAT VARIETIES INCLUDED IN THIS STUDY

Data arranged according to increasing wheat protein. All quantitative data on 13.5% moisture basis.

Lab. No.	Origin	Variety	Test weight	Flour yield	Absorption	Loaf volume	Texture[1]	Crumb color[2]	General appearance	
									Crust[3]	Symmetry[4]
			lbs./bu.	%	%	*cc.*				
HARD RED SPRING										
39–190	Mandan, N. D.	Vesta	61.2	73.5	57.8	490	6.0 C, o	6.8 y	S	3.0 o
–158	Langdon, N. D.	Premier	58.2	70.3	58.1	685	7.5	7.5	SlD	4.5 o
–149	Langdon, N. D.	Thatcher	55.5	69.9	59.6	880	6.5 o	7.0 y	SlD	4.5 o
–257	Hettinger, N. D.	Thatcher	57.7	68.2	59.7	940	6.0 o	7.0 y	S	4.5 o
HARD RED WINTER										
39–274	Kansas	Tenmarq	61.5	71.7	54.0	595	7.5	8.2	S	4.0 o
–276	Kansas	Chiefkan	61.8	73.0	58.4	655	6.5 o	7.5 g, y	S	4.2 o
–281	Nebraska	Cheyenne	63.2	72.1	55.1	655	7.2	7.8	S	4.0 o
–275	Kansas	Blackhull	61.0	68.5	55.7	715	7.0 o	7.8	S	4.5 o
–278	Nebraska	Nebred	59.8	68.3	53.8	780	7.0 o	7.2	S	4.5 o
–277	Kansas	Turkey	61.5	68.5	55.3	720	6.5 o	7.0 y	S	4.5 o
WHITE WHEAT										
39–116	Washington	Federation	60.8	66.0	52.2	440	3.5 C, o	5.0 g, y	P	2.0 o
–115	Washington	Early Baart	63.5	66.0	55.6	510	6.5 o	7.0 y	P	2.5 o
SOFT RED WINTER										
39–99	Indiana	Wabash	64.2	68.7	51.3	485	6.5 o	7.0 y	P	2.5 o
DURUM										
39–279	Mandan, N. D.	Mindum	60.2	69.9	54.6	490	4.5 C, o	4.5 y	Dull	2.5 o
EMMER										
39–280	Mandan, N. D.	Vernal	31.8	47.2	49.8	510	3.0 C, o	3.5 g	Dull	2.0

[1] Texture: o, open; C, coarse; c, close. Perfect score, 10.
[2] Color: y, yellow; gy, grey-yellow; g, grey. Perfect score, 10.
[3] Crust: D, dark; S, satisfactory; SlD, slightly dark; P, pale.
[4] Symmetry: o, overoxidized. Perfect score, 5.

From the results obtained with the hard red spring wheats, it is evident that a great disparity exists between the highest and lowest loaf volumes. The two Thatcher samples were outstandingly good, while the Premier sample was average in baking strength. The sample of Vesta, however, was of poor, unsatisfactory strength and yielded a loaf of low volume and inferior symmetry as compared to the other hard wheats. It should be pointed out that a number of the wheats grown at Mandan in 1939 did not measure up to the usual standard of North Dakota spring wheats as a result of climatic effects, and the inferior showing of this wheat should be attributed to unsatisfactory environmental conditions rather than entirely to heritable deficiencies in the variety. The protein content as shown in Table II was also low. The hard winter wheats did not show as great variability in loaf volume as the spring wheats. Nebred produced the largest loaf, while Chiefkan was decidedly inferior in crumb color. The test weights for this group of wheats were very satisfactory. The absorption was slightly lower than the average for the spring wheats. Chiefkan had the highest flour yield and water absorption of the group. These wheats were unfortunately not grown under comparable conditions and no doubt large variations in quality and properties were introduced by environmental differences. The relatively poor showing of Tenmarq could probably be attributed to lower protein content caused by such environmental factors. It produced, however, a loaf with the best crumb color in the entire series of wheats, and its texture rating was also relatively high. The white and soft wheats did not show up well in the baking test, owing principally to their low protein content. The durum and emmer also proved unsatisfactory in quality of bread produced, as might be expected from these types of wheat, which have been found unsuitable for the production of modern bread. The emmer had a very low test weight and flour yield, caused by the proportionately large outer husk of the kernel. This circumstance also led to the flour having a higher protein content than the wheat, as shown in Table II.

In Table II are shown the crude wheat and flour protein, flour ash, resistance values, the ratio of loaf volume to flour protein, and the specific volume (ϕ/C) as calculated from the viscosity data by the equation of Kunitz:

$$\eta/\eta_0 = \frac{1 + 0.5\ \phi}{(1 - \phi)^4}$$

where η is the coefficient of viscosity of the protein sol, η_0 the coefficient of viscosity of the dispersion medium, ϕ the percentage of the system occupied by the volume of the disperse phase, and C concentration of the disperse phase. These specific volumes, or the

volume occupied by 1 g. of protein, are the average values computed for each wheat variety, and there are accordingly a number of observations included in each. The use of the average value seemed to be justified inasmuch as no great variability was evident among the

TABLE II

WHEAT AND FLOUR PROTEIN, ASH, RESISTANCE VALUES, AND SPECIFIC VOLUMES

Data arranged in order of increasing wheat protein within class.

Lab. No.	Variety	Origin	Crude protein (N X5.7)		Ash	Resistance value	Loaf vol./protein content	Specific volume
			Wheat	Flour				
			%	%	%	*sec.*		*φ/C*
			HARD RED SPRING					
39–190	Vesta	Mandan, N. D.	11.6	11.3	0.48	81.4	43.40	7.97
–158	Premier	Langdon, N. D.	15.3	15.0	0.54	73.0	45.66	7.91
–149	Thatcher	Langdon, N. D.	16.4	16.0	0.52	82.4	55.00	7.93
–257	Thatcher	Hettinger, N. D.	17.5	17.3	0.51	86.0	54.34	7.46
			HARD RED WINTER					
39–274	Tenmarq	Kansas	14.1	13.2	0.38	70.0	45.08	7.62
–276	Chiefkan	Kansas	15.8	15.3	0.43	56.8	42.81	7.11
–281	Cheyenne	Nebraska	16.2	14.6	0.47	81.0	44.86	7.44
–275	Blackhull	Kansas	16.2	15.8	0.45	49.4	45.25	7.53
–278	Nebred	Nebraska	16.9	16.2	0.42	71.0	48.15	7.80
–277	Turkey	Kansas	17.2	16.9	0.58	45.8	42.60	7.10
			WHITE WHEAT					
39–116	Federation	Washington	10.8	9.3	0.40	106.0	47.31	7.60
–115	Early Baart	Washington	11.1	9.7	0.44	75.6	52.58	7.96
			SOFT RED WINTER					
39–99	Wabash	Indiana	10.1	8.6	0.48	61.0	56.40	6.94
			DURUM					
39–279	Mindum	Mandan, N. D.	15.3	14.6	0.56	53.8	33.56	5.82
			EMMER					
39–280	Vernal	Mandan, N. D.	12.9	16.8	0.68	29.0	30.36	6.28

specific volumes for each wheat. No consistent trends toward a change in hydration with increasing protein concentration were noticeable. The ratio of loaf volume to flour protein was calculated to obtain a value more representative of the baking quality of the

wheats, inasmuch as some of the samples possessed a high protein content but would yield poor loaves because of inferior gluten quality, while other samples would be penalized as a result of low protein content although the gluten quality might be very high.

A substantial range in wheat protein content is evident, varying from 17.5% for one of the Thatcher samples to 10.1% for Wabash, a difference of 7.4%. The corresponding flour protein range was from 17.3% to 8.6%, a difference of 8.7%. The range in ash content was from 0.68% to 0.38%, a difference of 0.30%. The emmer was extremely difficult to mill and this fact, no doubt, tended to increase the ash for this particular sample. Tenmarq produced the lowest flour ash of any of the wheats. The resistance values, as determined on the "tenderness tester," represent the time in seconds for the plunger of the instrument to compress the gluten sample to a thickness of 0.175 inch and was calculated from a curve traced by a kymograph. This method of calculation has been explained by Harris and Johnson (1940a). The stiffer the gluten, the longer this time will be, while a relatively short time in seconds denotes a soft nonresistant gluten. Federation, a soft white variety grown in the state of Washington, had the most resistant gluten, being substantially higher in this respect than the other samples. The sample of emmer, on the other hand, had a soft gluten and the plunger was able to compress this gluten quite readily. The hard red winter wheat varieties showed a surprising variability in this gluten property, ranging from 81.0 seconds for Cheyenne to 45.8 seconds for Turkey. No relationship between this value and the commonly accepted quality ratings of the hard wheats is evident from the data. It appears, however, that the hard red spring wheats as a class have more resistant glutens than the hard red winter wheats.

The ratio of loaf volume to flour protein does not show the differences that are evident in the loaf volumes. This would be expected, since the variability in flour protein will in many cases largely compensate for the loaf-volume differences. The durum and emmer values are, however, distinctly lower than the ratios for the other samples.

The specific volumes, shown in the right hand column of Table II, vary appreciably among the different classes. The hard red spring wheats appear to be slightly higher in specific volume than the hard red winters. The white wheats also are high in this gluten property. The last three wheats in the table, the soft winter, durum, and emmer, are distinctly lower in specific volume. It is evident from these data that this property of the white wheat glutens is quite different from

the specific volume of the soft red winter wheat gluten micelles and resembles the hard wheats.

The data obtained from the viscosity determinations are presented in the form of curves rather than in the form of tables, for greater ease of interpretation. Figure 1 shows the relationship between viscosity and protein concentration for representative samples of different classes. Average values were calculated for each of the hard wheat

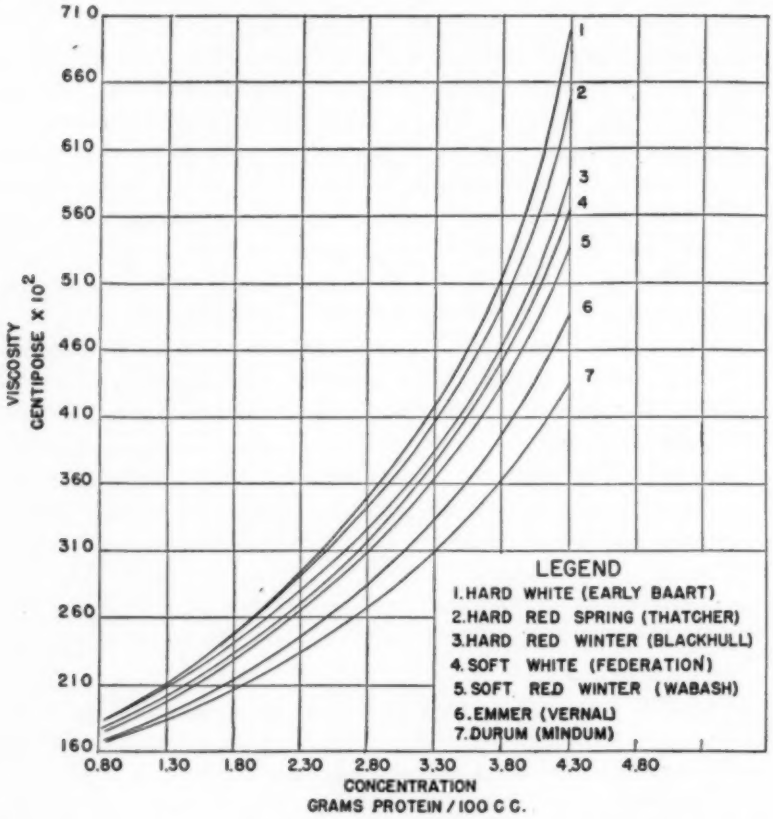

Fig. 1. Relationship between viscosity and gluten protein concentration in different wheat classes.

classes and the variety having the viscosity curve most similar to the average of the class was chosen to represent the class, since it would be clearly impossible to present in one figure the data from all the wheats studied without hopelessly confusing the picture. The curves show that Early Baart, a hard white wheat, has the highest viscosity of the wheats investigated. The hard red spring wheat has the second-highest viscosity, followed at an interval by the hard red winter wheat. Federation, a soft white wheat, has a curve intermediate in

position between the curves obtained from the hard red winter wheat and Wabash, a soft red winter wheat. Emmer has the second lowest and durum the lowest viscosity of the various classes investigated. The viscosity curves of the sodium salicylate gluten dispersions of these two latter wheats appeared to show marked divergence from the

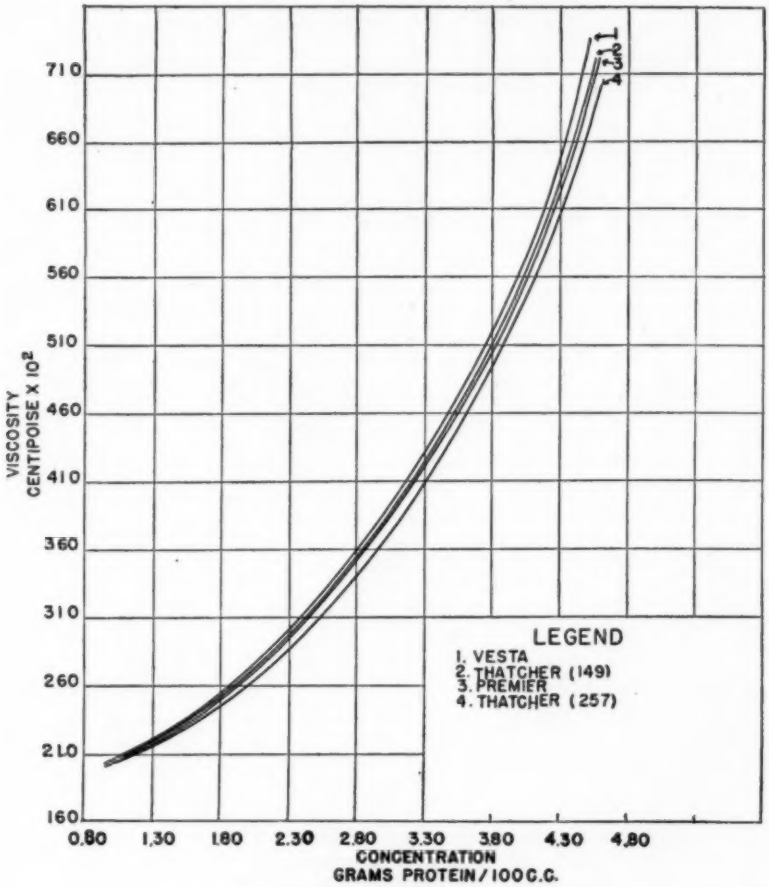

Fig. 2. Relationship between viscosity and gluten protein concentration for hard red spring wheats.

curves of the other wheats presented in the figure, and are no doubt connected with fundamental genetic differences. In many instances it will be found that hard red winter wheats give gluten dispersions of viscosities equal to those of some of the hard red spring wheats.

In the instances of soft red winter, emmer, and durum wheats these differences in the viscosity curves are due, no doubt, to a progressive decrease in size of the gluten micelle as shown in the specific

volume data presented in Table II. It would appear that the white wheats tend to have larger protein micelles in their gluten dispersions than would be expected from their relative baking strengths.

Figure 2 represents the viscosity-concentration curves obtained from the sodium salicylate dispersions of the hard red spring wheat

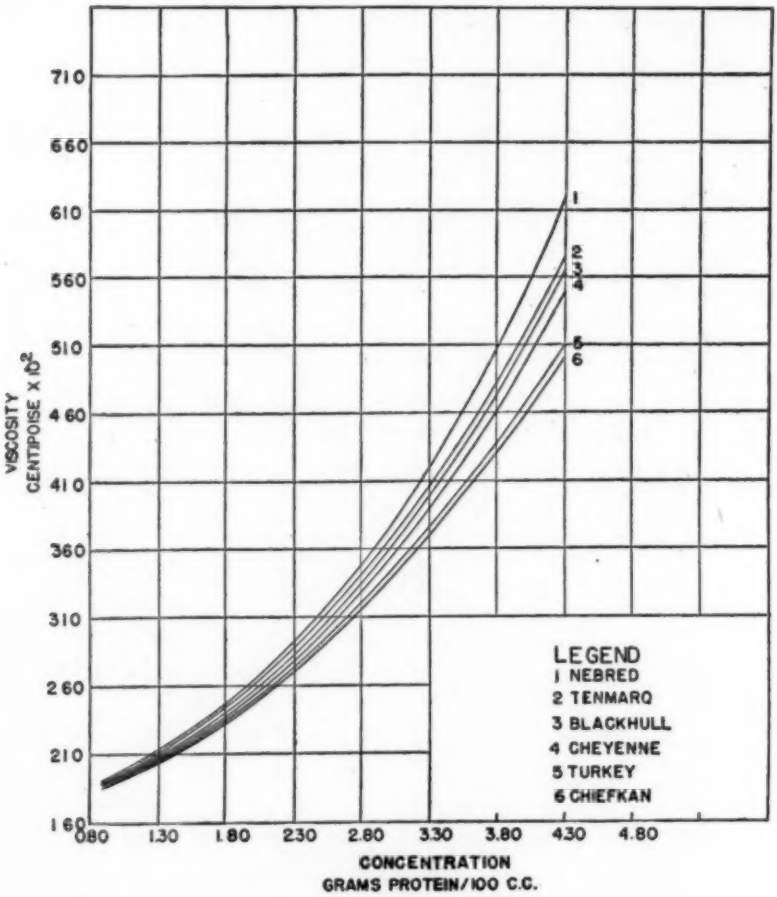

Fig. 3. Relationship between viscosity and gluten protein concentration for hard red winter wheats.

glutens. Only minor differences are shown in spite of the great disparity in loaf volume between Vesta and Thatcher. It would be expected, from a knowledge of its baking behavior and the "feel" of the gluten during the washing process, that Vesta had the gluten present in a more or less coagulated condition and that accordingly a high viscosity curve would result. Such a picture, however, is not found in Figure 2 in view of the small differences shown in the viscosity-

concentration relationships. It is therefore evident that, while class differences may be defined by these curves derived from viscosity studies on wheat-gluten dispersions, differences in baking strength within the class would not be shown. No significant differences in specific volumes of the micelles in dispersions prepared from various hard red spring wheats were to be noted.

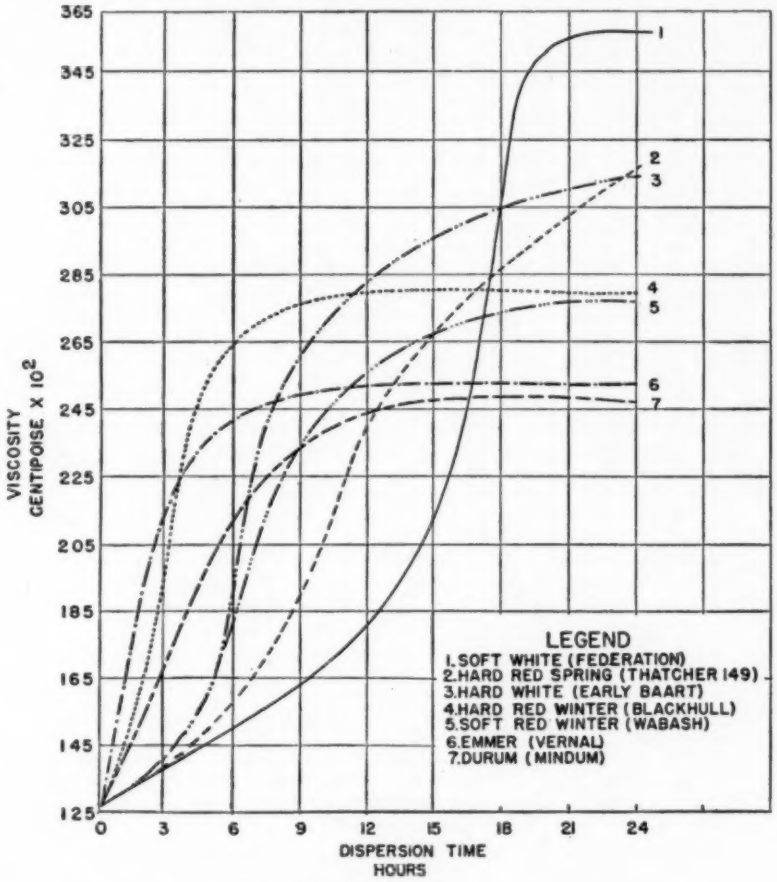

Fig. 4. Increase of viscosity with time of dispersion—glutens prepared from wheats of different classes.

Figure 3 shows the viscosity-concentration curves for the hard red winter wheat varieties. Nebred has the highest curve and is very close to the average value for the hard red spring wheats. Tenmarq is next in order of viscosity, while Blackhull and Cheyenne are similar. It was rather surprising to find Turkey distinctly below the first four varieties and quite close to Chiefkan in viscosity values. In similar

investigations with 1938 crop samples, Harris and Johnson (1940) found that a sample of Kansas Turkey ranked very close to the hard red spring wheats in respect to the viscosity-concentration curves, and was substantially higher than a Chiefkan sample. In the present instance the lower position of the curves of these two varieties is due to significantly smaller gluten protein micelles as compared with the other hard winter wheat varieties.

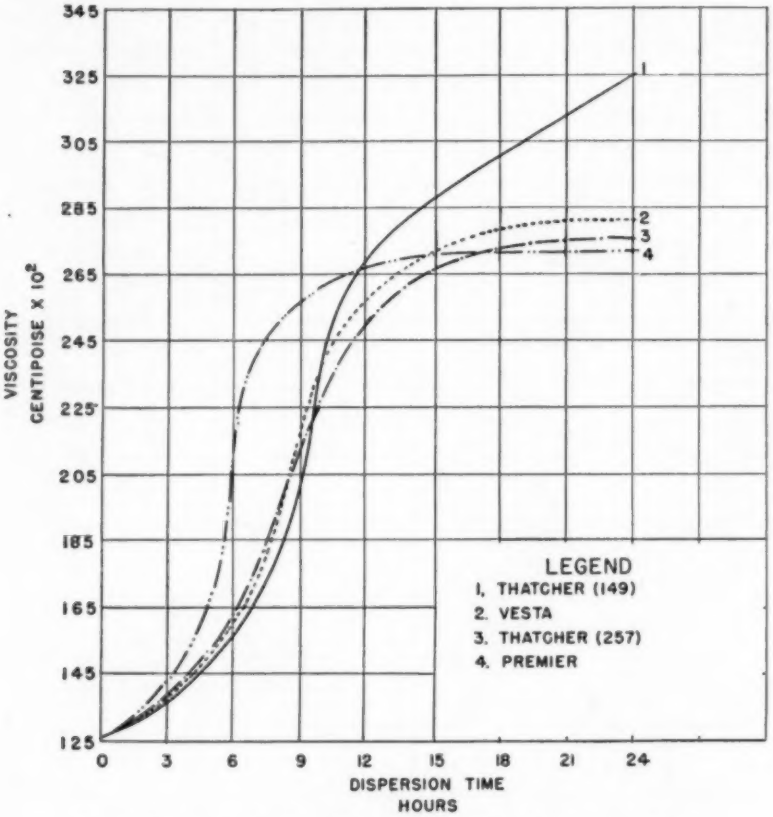

Fig. 5. Increase of viscosity with time of dispersion—glutens prepared from hard red spring wheats.

Figure 4 shows the relative dispersion rates obtained on glutens prepared from wheats representative of the different types included in the study. These glutens were washed from doughs made up from the standard basic formula with 5% of sucrose and the glutens were washed immediately after the completion of mixing of the doughs. It is at once apparent from the figure that large differences exist among the wheats in respect to gluten-dispersion rate. Federation gluten was very resistant, at first, to dispersion, but it disintegrated at a

rapid rate after approximately 15 hours in the shaker, and reached the highest viscosity of this series of dispersions. The hard red spring wheat gluten was next in order of resistance but the shape of the curve was quite different from that of Federation and shows a more consistent rate of dispersion. The soft red winter wheat gluten was next in order of dispersibility, while Early Baart, although similar at first, showed more resistance after the sixth hour. Emmer and Blackhull

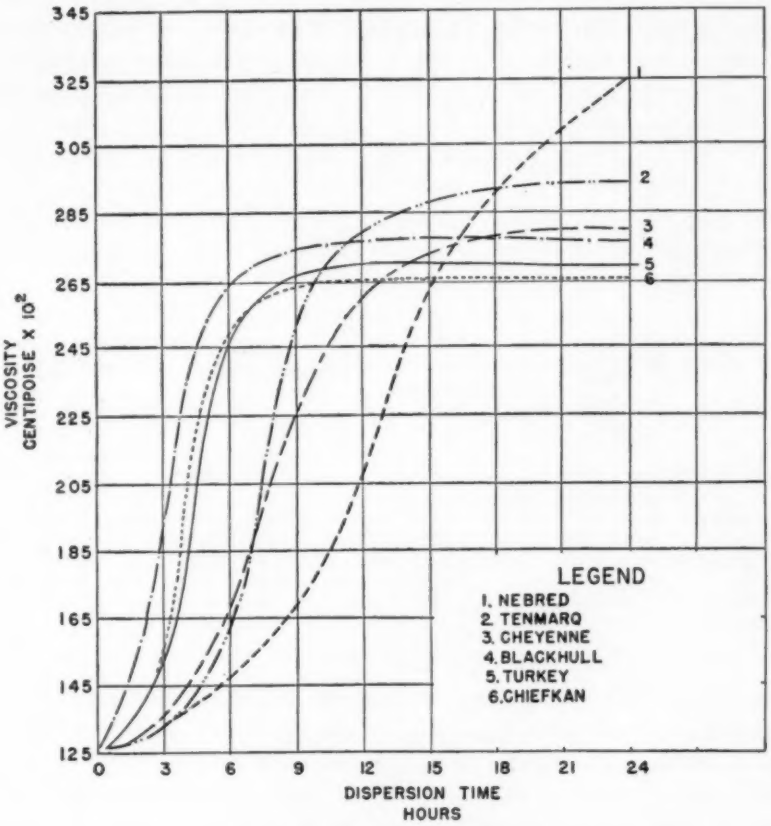

Fig. 6. Increase of viscosity with time of dispersion—glutens prepared from hard red winter wheats.

dispersed rapidly, while the durum gluten dispersed more slowly than either. It is evident that Federation has a gluten definitely different from the other wheats represented, in respect to dispersibility in 10% sodium salicylate. It is probable that the state of protein aggregation, or particle size, is related to dispersibility, the larger particles being more resistant.

Figure 5 represents the dispersion rates of the four hard red spring wheat glutens prepared as in the previous instance. The curves are,

to some extent, similar in their general characteristics, especially if the variety Premier is excepted. This is a new variety that has not been distributed in North Dakota and has generally been found to be of lower baking strength than the other two varieties represented. It shows a tendency to disperse more readily than the other hard red spring samples. The sample of Vesta, in spite of its unsatisfactory showing in the baking test, was very similar to the Thatcher sample in respect to dispersibility.

In Figure 6 the results obtained with the hard red winter wheat varieties are presented. Nebred, a comparatively unknown variety, is the most resistant to dispersive action and resembles the spring wheats in this particular. Tenmarq and Cheyenne are somewhat similar, but the former appears to disperse at a lower rate subsequent to the seventh hour. The remaining three varieties apparently fall into a group of very similar dispersibility, but Blackhull has the least resistance. This behavior is probably linked with the low mixing tolerance of this variety.

TABLE III

TABLE OF STATISTICAL CONSTANTS—MEANS, STANDARD DEVIATIONS, AND COEFFICIENTS OF VARIABILITY

Variables	Means	Standard deviations	Coefficients of variability
Flour protein, %	14.04	2.832	20.17
Loaf volume, *cc.*	636.67	147.509	23.17
Viscosity, *centipoises* $\times 10^2$	319.02	94.778	29.09
Fractionation value	1410.20	669.862	47.50
Resistance value, *seconds*	68.15	18.538	27.20
Specific volume, ϕ/C	7.36	0.609	8.27

In Table III are shown the means, standard deviations, and coefficients of variability computed from the data. With the exception of the specific volume, the results indicate a high degree of variability among the wheats in respect to the values determined. The quantity of protein removed from the dispersions by 6% (by volume) of concentrated $MgSO_4$ solution was more variable than any other value examined.

Table IV presents the correlation coefficients which were calculated between the more pertinent variables considered in this investigation. The relationship between viscosity and fractionation value is extremely high and justifies the prediction of the latter variable from a knowledge of the former. Similar conclusions were reached by the authors in a previous study (Harris and Johnson, 1940a), who found values of $+ .8392$ ($N = 30$) and $+ .9592$ ($N = 35$) for this relationship. There

are also significant positive correlations between flour protein and loaf volume, resistance value and specific volume, resistance value and loaf volume/flour protein, as well as between the latter ratio and specific volume. In other words, the larger the specific volume, the higher the ratio and the greater the resistance of the gluten to compression. Because of extreme divergence in baking quality due to the inclusion of wheats of inferior baking strength in the study, it was not thought advisable to determine the correlation between these variables and flour protein or loaf volume, but rather to use the ratio of loaf volume to flour protein. The results of this study lead to the concept that larger micelles are present in the glutens of wheats of superior baking quality, but the reservation must be made that this relationship does not appear to be valid for varieties within the better quality bracket.

TABLE IV

CORRELATION COEFFICIENTS COMPUTED FROM THE DATA

Significant correlation coefficients are in bold type.

Variables correlated		Correlation coefficient	Probability
X	*Y*	r_{xy}	*P*
Flour protein, %	Loaf volume, *cc.*	**+.7251**	<.0001
Viscosity, *centipoises* $\times 10^2$	Fractionation value	**+.9706**	<.0001
Flour protein, %	Resistance value, *seconds*	+.0424	>.5542
Resistance value, *seconds*	Loaf volume, *cc.*	+.0966	>.5542
Resistance value, *seconds*	Specific volume, ϕ/C	**+.6518**	.0084
Resistance value, *seconds*	Loaf volume/flour protein	**+.6007**	.0179
Loaf volume/flour protein	Specific volume, ϕ/C	**+.6604**	.0074

A direct relationship between the specific volume of the gluten micelle in 10% sodium salicylate and dispersibility does not seem to be indicated by the results. The durum and vernal emmer, however, which have the smallest specific volumes, also tend to possess a high dispersion rate. It must be borne in mind with respect to the results obtained upon protein dispersions in sodium salicylate that the environment surrounding the protein micelle is different from that which exists in the native condition. There is reason to suspect that chemical combination may exist between the protein particle and sodium salicylate molecule, which may alter, to some extent, the size and configuration of the particle but should not change the relative size of the particle from different wheat glutens. At least it has been shown by Rose and Cook (1935) and Cook and Rose (1935, 1935a) that solutions of sodium salicylate caused little denaturative changes in gluten as compared to the solvents, acid and alkali.

The resistance of the washed gluten, as determined by a "tenderness tester," was not related to loaf volume but was correlated with the ratio of loaf volume to flour protein and with specific volume in this investigation. It is doubtful whether this test has any utility for purposes of determining baking strength, inasmuch as the baking test would differentiate wheats of different strengths in a more precise and readily understandable manner. It may have a certain limited value as a supplementary test to determine the effects of proteolytic action or dough fermentation upon certain physical properties of the gluten.

The measurement of rate of gluten dispersion in 10% sodium salicylate solution during constant, gentle agitation, appears to yield as informative results in relation to fundamental gluten quality as any test described in this paper. It appears to offer possibilities as a means of supplementing the baking test with additional and intimate information regarding gluten quality. Further investigations are in progress to clarify these relationships and to delimit more clearly the applicability of the test.

Summary and Conclusions

Glutens were washed from doughs prepared from 15 flours experimentally milled from wheats comprising varieties of the hard red spring, hard red winter, soft red winter, durum, and white wheat classes, and emmer. The flours were also baked by the malt-phosphate-bromate method. A large range in baking strength was covered by the 15 wheats included.

Viscosity studies were conducted upon the glutens dispersed in 10% sodium salicylate solution using an Ostwald capillary pipette at 25°C. The protein concentrations of these dispersions were determined and viscosity-concentration curves constructed. The hydrodynamic and specific volumes of the protein micelles were calculated by an application of the equation of Kunitz. The hard red spring wheats had higher viscosity on the average than the hard red winter wheats, while the soft red winter was the lowest of the three. Emmer was next lowest to the soft red winter in respect to viscosity, while durum was the lowest of the wheats studied. Early Baart, a hard white wheat, had the highest viscosity of any variety in the study.

The relative placing of the soft red winter, emmer, and durum wheats in relation to the viscosities of their dispersions at equal protein concentrations appeared to be due to a progressive decrease in micelle size with consequent decrease in viscosity, as shown by the values computed for their specific volumes. No significant differences are shown among the four red spring wheat varieties studied, but in the

hard red winter wheat class, Turkey and Chiefkan fell below the other four samples in the viscosity and specific volume of the gluten particles in 10% sodium salicylate dispersion. Gluten dispersion rates in sodium salicylate were obtained and graphs constructed to represent the differences between classes and varieties. Large differences are evident between wheat classes as well as between some of the hard red winter wheat varieties. The hard red spring wheats did not show any very marked differences, however. Nebred, a comparatively new variety, was the most resistant to dispersive action, while Blackhull had apparently the least resistance. Turkey and Chiefkan were similar. No consistent changes of specific volume with increasing protein concentration were shown by the data.

While the hydrodynamic or specific volume of the protein particles of these wheats in sodium salicylate colloidal solution does not appear to be definitely connected with their dispersibility in sodium salicylate, it is nevertheless evident that the soft red winter Wabash, emmer, and durum have significantly lower specific volumes in their dispersions and would have the highest dispersion rates. It would also appear that the varieties of wheat that are resistant, or have a high degree of mixing tolerance, will have a relatively low dispersion rate. Wheats that lack mixing tolerance will tend to be easily dispersed in 10% sodium salicylate. A measurement of gluten resistance to compressibility as determined upon the "tenderness tester" did not appear to yield pertinent information in regard to quality differences. The baking test appeared to be more sensitive to variety differences and also appeared to yield data more readily interpreted into quality concepts.

The determination of fractionation value, or the quantity of protein removed from the dispersions by the addition of a definite concentration of $MgSO_4$, was highly related to the viscosity of the corresponding colloidal solutions. In view of the labor and reagents involved in the measurement of fractionation value as contrasted with the determination of viscosity, it would seem that viscosity determinations alone should be satisfactory to use in studies of this nature.

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BOOK REVIEW

What Are the Vitamins? By Walter H. Eddy. Published by Reinhold Publishing Company, New York, N. Y. 230 pages. 1941. Price $2.50.

This book, in the words of the author, is an expression of his personal views of what seems pertinent and reliable information from past and current investigations in the vitamin field. The author has assembled, condensed, and presented a great deal of information selected from the enormous volume of literature on vitamins. The book naturally assumes some knowledge of chemistry and biology on the reader's part, as it would be quite impossible to discuss, for instance, the pathological aspects of the vitamin deficiencies in ordinary lay language.

The book encompasses thirteen chapters, giving first the historical background of development of the vitamin field, accompanied by a brief review of all the vitamins, including those isolated and those postulated. This section is followed by a discussion of the mode of action of various vitamins, including the biological processes or reactions they enter into. A number of structural formulas are given here but it is regrettable that many errors appear in their presentation. These errors detract seriously from the value of the book as a handy reference. In some respects the text contains gaps in continuity which make it somewhat difficult to follow.

The next section discusses the physiological properties of the vitamins and the effects caused by a deficiency of a particular vitamin in the diet. It also lists the consensus of expert opinion regarding daily human requirements for each vitamin.

The chapters following are devoted to the functions and properties of each of the several vitamins. Many references to published scientific literature are used in the text with a corresponding bibliography at the end of each chapter. This part of the book should prove very useful to those wishing to make a survey of the vitamin literature.

Appendix A is more or less a recapitulation of the chemical nature and structural formulas of the vitamins presented earlier in the text. Again, a few inaccuracies in structural formulas occur but not as seriously as those in Chapter II. Appendix B is a table of vitamin values of common foodstuffs along with definitions of vitamin units and equivalents in weight of the pure chemical compound wherever this is possible.

Good author and subject indexes are provided.

G. Ivor Jones

BOOKS ON SOILLESS GROWTH OF PLANTS

Aside from the present popular interest in growing plants without soil, the possibilities that the several techniques offer for studying the relationships between plant nutrition and the characteristics of cereal grains merit attention. A number of workers have already demonstrated that soil fertilization markedly influences the quantities of protein and phosphorus in wheat and wheat flour. The effect of fertilizer treatments on the "quality" of the wheat and flour constituents is still problematical, but it is not unreasonable to assume that here too there must be a relationship.

The small-scale sand and water culture equipment used in the past has limited the amount of wheat produced under absolutely controlled nutrition to quantities

insufficient for adequate milling and baking. During the past few years techniques have been developed that facilitate production on such a scale that large samples of grain may be made available. A combination of present micro methods of milling and baking with large-scale nutrient culture now seems to be practical. Such a technique offers an approach which may well solve many of the problems associated with determining the relationship between plant nutrition and baking quality of the resulting grain. It is with this thought in mind that reviews of the following five books are presented for the attention of cereal chemists.

Chemical Gardening for the Amateur. By Charles H. Connors and Victor A. Tiedjens. Published by Wm. H. Wise & Co., New York, N. Y. 1939. 255 pages. Price $1.95.

This book should prove very valuable to the amateur "chemical gardener." It is written particularly for those interested in the hobby of growing plants without soil. However, the excellent illustrations, good binding, and wealth of material applicable to amateur gardening of all kinds make it a welcome addition to any book shelf. Too, an attempt is made to correct some of the prevalent misconceptions regarding soilless growth of plants.

The authors' authoritative discussion is supported by a high degree of accuracy in their factual material. In addition the presentation is good and the book is entirely readable. Of the nine chapters, five deal specifically with chemical gardening and, of these, three give detailed information and methods. The remaining chapters are more general in nature and in them the authors present a little philosophy, some condensed plant physiology, and a lot of practical information for amateur gardeners. The authors' viewpoint is that chemical gardening is valuable chiefly as a hobby and their discussion is, therefore, of particular value for those interested in that aspect. There is some deficiency in detail as regards the setting up of any particular method, which deficiency would handicap a worker interested more in mass production than in experimentation with methods. Appendices containing planting information, weights and measures, glossary, and index make the book complete.

Soilless Growth of Plants. By Carleton Ellis and Miller W. Swaney. Published by Rheinhold Publishing Corporation, New York, N. Y. 1938. 155 pages. Price $2.75.

One of the first books to be published dealing entirely with soilless gardening, this book satisfied a definite need at the time. In spite of more recent contributions it still serves its purpose as an excellent introductory text for the beginner. It offers an interestingly written survey of the various phases of nutrient culture but, like several other books on the same subject, suffers as a result of the attempt to crowd too much material into a small volume.

In addition to chapters dealing specifically with water culture, aggregate culture, and nutrient formulas, an introduction is given to such subjects as general plant physiology, plant diseases, and special chemicals such as plant hormones. Particular attention is given to the applications of soilless gardening methods both in the home and in commercial greenhouses. The placing of such suggested applications into practice is facilitated by the excellent illustrations provided.

In addition to the somewhat too great enthusiasm as to the possibilities of soilless growth of plants, the manner of presentation is to some extent objectionable. Entirely too much information is crowded into a small space, resulting in inadequate and often confusing treatment. Because of this, those chapters not dealing directly with nutrient culture detract from, rather than add to, the value of the book.

The Complete Guide to Soilless Gardening. By W. F. Gericke. Published by Prentice-Hall, Inc., New York, N. Y. 1940. 285 pages. Price $2.75.

Credit for realizing the commercial possibilities of water culture of plants and for popularizing the method must be given to Dr. Gericke. This book presents to many readers their first opportunity to find out what the author has been doing and what methods he proposes. As such, it is a valuable contribution. Further value lies in his illustrations of the wide variety of crops which have been grown by water culture and in the suggestion that the method may be an effective aid for studying the relationship of nutrition to baking quality of wheat. However, the book is offered as a "complete guide" to soilless gardening, whereas it may be considered as such only if the reader accepts the author's tenet that water culture, or "hydro-

ponics," is the only true soilless gardening. Little information relative to the more popular aggregate culture (sand, gravel, cinders) is included.

For those interested in production by large-scale water culture the book should be considered as essential equipment. Its twenty-one chapters cover everything from the best type of joints to use in wooden tanks to a discussion of the pH scale. However, many of the details pertinent to hydroponics are obscured by reason of poor organization and inclusion of much extraneous material not essential to successful practice of the method. The book is well illustrated and has an adequate glossary of technical terms.

The reader should be cautioned that many of the views expressed in the comparisons of soil and water culture are those of the author and are not necessarily accepted by other workers. Particularly is this true of comparisons regarding the economics of production and the yield and quality of the product. The economic practicability of large-scale outside water culture is very questionable except under very unique environmental conditions. Attention should be drawn to an error in the discussion of figure 9. The small seedlings with long roots are obviously those produced by low, not high, nitrogen intake.

Gardening without Soil. By A. H. Phillips. Published by Chemical Publishing Co., Inc., New York, N. Y. 1940. 137 pages. Price $2.00.

This is a very well organized and well written book. It is intended primarily for the use of soilless gardeners in the British Isles. However, with the exception of such material as a list of the English firms which can supply the necessary equipment, the content is applicable to American conditions. As much specific information as is found in some of the longer books is concisely and entertainingly presented. The author stays close to his subject and does not make his book a conglomeration of plant physiology, horticulture, and a number of other subjects.

The six chapters progress logically from a short introduction on "How Plants Grow" through water culture, aggregate culture, nutrient solutions, and the practice of soilless culture, to "Soilless Culture on the Farm." This last chapter on the use of nutrient culture in farming seems somewhat out of place, since it deals with the production of sprouted grain for forage. However, this is an important practice and the use of nutrient solutions to increase the feeding value of the product is an endeavor well worth describing. A scientific paper dealing with the production of horticultural crops by water culture is reprinted as an appendix. The appended bibliography is of value but the book suffers from lack of both an index and a glossary of technical terms.

Growing Plants in Nutrient Solutions. By Wayne I. Turner and Victor M. Henry. Published by John Wiley and Sons, Inc., New York, N. Y. 1939. 154 pages. Price $3.00.

This book is written primarily as an aid to the commercial greenhouse grower. The senior author has had much commercial greenhouse experience and it is stated that in 1939 he had over 70,000 square feet of greenhouse space in nutrient culture. The reviewer's opinion is that no commercial greenhouse man should attempt to convert part or all of his bench space to soilless culture without this book as a guide. In addition much of the information is of value to both amateur and technical experimenters in the field. The book is complete in every respect, including appendices listing sources of equipment and materials and providing a bibliography, sample greenhouse record sheets, and a combined index and glossary.

The first four chapters deal with methods of nutrient culture, their advantages in greenhouse production, and detailed instructions for installation of the widely used subirrigated aggregate culture. Of the remaining eight chapters, four are devoted to the preparation and testing of nutrient solutions, two to rudimentary plant physiology, one to the diagnosis of deficiency symptoms, and one to general cultural conditions. Illustrations are adequate and assist in gaining an appreciation of the method. The considerable discussion of the practical, large-scale regulation of plant growth by modification of the potassium-nitrogen ratio in the nutrient is very welcome. Beginners especially will find the "keys" for diagnosing plant-deficiency symptoms instructive. Altogether an outstanding contribution has been made in bringing before greenhouse men generally this description of nutrient culture in practice.

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